1973
YEARBOOK OF ASTRONOMY

EDITED BY
PATRICK MOORE

1973
Yearbook of Astronomy

Edited by

PATRICK MOORE

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Editorial

The *Yearbook* has now been published for thirteen years, and there seems little to add to what has been said in previous Editorials; but I must repeat my thanks to Dr. J. G. Porter, who has made his usual essential contribution, and to both the British and United States publishers. Again, too, the line drawings have been skilfully executed by Lawrence Clarke. In the Article Section we again welcome some of our familiar contributors together with some distinguished newcomers. We hope that the result will continue to be acceptable!

PATRICK MOORE

Selsey, 1972.

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WRIGHT, H. N. D. *The Surface of Saturn:* 1964.

Preface

New readers will find that all the information in this *Yearbook* is given in diagrammatic or descriptive form; the positions of the planets may easily be found on the specially designed star charts, while the monthly notes describe the movements of the planets, and give details of other astronomical phenomena that may be observed from these latitudes. The reader who needs more detailed information will find *Norton's Star Atlas* (Gall and Inglis) an invaluable guide, while more precise positions of the planets and their satellites, together with predictions of occultations, meteor showers and periodic comets may be found in the *Handbook* of the British Astronomical Association. A somewhat similar publication is the *Observer's Handbook* of the Royal Astronomical Society of Canada, and readers will also find details of forthcoming events given in the American *Sky and Telescope* (which also publishes complete details of all occultations visible in North America) and in the British quarterly periodical *Astronomy and Space* (David and Charles).

Important Note

The star charts are drawn, and the notes are, in general, designed for use in latitude 52 degrees north, but may be used without alteration throughout the British Isles, and (except in the case of eclipses and occultations) in other countries of similar north latitude.

The times given on the star charts and in the Monthly Notes are generally given as local times, using the 24-hour clock, the day beginning at midnight. Ignoring small differences of longitude, this local time may be taken as Greenwich Mean Time (G.M.T.) in the British Isles, or as the appropriate Standard

Time in other Time Zones. If Summer Time is in use, the clocks will have been advanced by one hour, and this hour must be subtracted from the clock time to give G.M.T.

The times of a few events (e.g., eclipses) are given in G.M.T., and this may be converted to Local Mean Time by subtracting the west longitude (or adding the east longitude).

Local Mean Time = G.M.T. − West Longitude

Similarly,

Eastern Standard Time = G.M.T. − 5 hours,
Central Standard Time = G.M.T. − 6 hours, etc.

PART ONE

Events of 1973

Monthly Charts and Astronomical Phenomena

Notes on the Star Charts

The stars, together with the Sun, Moon and planets, seem to be set on the surface of the celestial sphere, which appears to rotate about the Earth from east to west. Since it is impossible to represent a curved surface accurately on a plane, any kind of star map is bound to contain some form of distortion. But it is well known that the eye can endure some kinds of distortion better than others, and it is particularly true that the eye is most sensitive to deviations from the vertical and horizontal. For this reason the star charts given in this volume on pages 20 to 45 have been designed to give a true representation of vertical and horizontal lines, whatever may be the resulting distortion in the shape of a constellation figure. It will be found that the amount of distortion is, in general, quite small, and is only obvious in the case of large constellations such as Leo and Pegasus, when these appear at the top of the charts, and so are drawn out sideways.

The charts show all stars down to the fourth magnitude, together with a number of fainter stars which are necessary to define the shape of a constellation. There is no standard system for representing the outlines of the constellations, and triangles and other simple figures have been used used to give outlines which are easy to follow with the naked eye. The names of the constellations are given, together with the proper names of the brighter stars. The apparent magnitude of the stars are indicated roughly by using four different sizes of dots, the larger dots representing the bright stars.

There are four such charts at each opening, and these give a complete coverage of the sky up to an altitude of 62½ degrees; there are twelve such sets to cover the entire year. The upper two charts show the southern sky, south being at the centre; the coverage is 200 degrees in azimuth, from a little north of east (top left) to a little north of west (top right). The two lower charts show the northern sky, from a little south of west (lower left) to a little south of east (lower right). There is thus an overlap east and west.

The charts have been drawn for a latitude of 52 degrees, but may be taken without appreciable error to apply to all parts of the British Isles. They will also be equally suitable for any other part of the world having a north latitude of about 52 degrees — e.g. parts of Europe and Asia, and Canada. In such cases the times given must be taken as local time, and not G.M.T., which applies only to the British Isles.

Because the sidereal day is shorter than the solar day, the stars appear to rise and set about four minutes earlier each day, which amounts to two hours in a month. Hence, the twelve sets of charts are sufficient to give the appearance of the sky throughout the day at intervals of two hours, or at the same time of night at monthly intervals throughout the year. The actual range of dates and times when the stars on the charts are visible is indicated at the top of each page. This information is summarized in the following table, which gives the number of the star chart to be used for any given month and time.

G.M.T.	16^{h}	18^{h}	20^{h}	22^{h}	0^{h}	2^{h}	4^{h}	6^{h}
January	10	11	12	1	2	3	4	5
February		12	1	2	3	4	5	6
March			2	3	4	5	6	
April			3	4	5	6		
May			4	5	6	7		
June			5	6	7			
July			6	7	8	9		
August			7	8	9	10	11	
September		7	8	9	10	11	12	
October		8	9	10	11	12	1	
November	8	9	10	11	12	1	2	3
December	9	10	11	12	1	2	3	4

The charts are drawn to scale, and estimates of altitude and azimuth may be made from them. These values will necessarily be mere approximations, since no observer will be exactly on the meridian of Greenwich at 52 degrees latitude, but they will generally serve for the identification of stars and planets. The horizontal measurements, marked at every ten degrees, give the azimuths (or true bearings) measured from the north round through east (90 degrees), south (180 degrees), and west (270 degrees). The vertical measurements, similarly marked, give the altitudes of the stars up to 62½ degrees.

The ecliptic is drawn as a broken line on which the longitude is marked at every ten degrees; the positions of the planets at any time are then easily found by reference to the table immediately following the star charts on page 46.

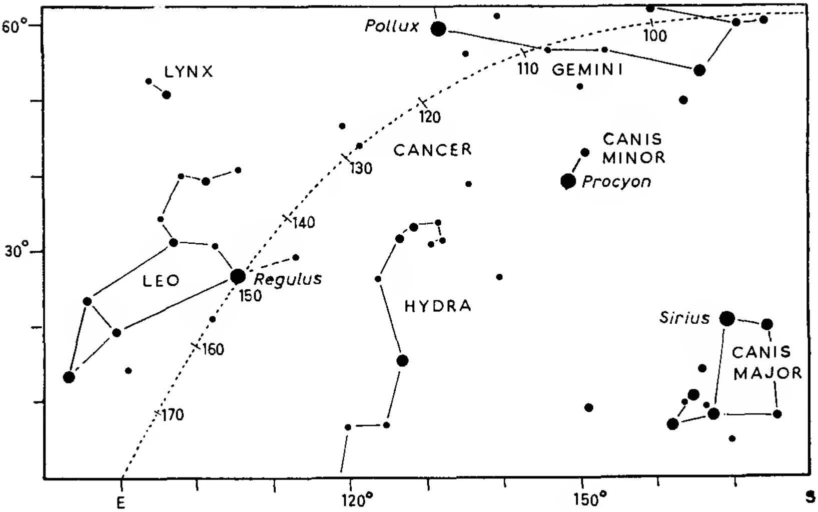
There is a curious illusion that stars at an altitude of 60 degrees or more are actually overhead, and the beginner may often feel that he is leaning over backwards in trying to see them. These high-altitude stars, being nearer the pole, move more slowly across the sky, and a different kind of map may therefore be used. These overhead stars are given separately on pages 44 and 45, the entire year being covered at one opening. Each of the four maps shows the overhead stars at times which correspond to those of three of the main star charts. The position of the zenith in latitude 52 degrees is indicated by a cross, and this cross also marks the centre of a circle which is 35 degrees from the zenith, and which therefore indicates an altitude of 55 degrees; there is thus a small overlap with the main charts.

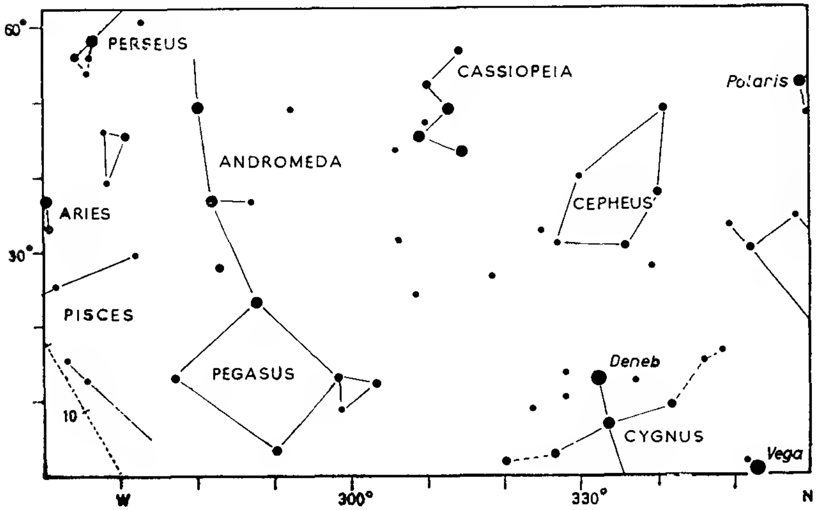
The broken line leading from north to south is numbered to indicate the corresponding main chart. Thus on page 44 the N–S line numbered 6 is to be regarded as an extension of the S line of chart 6 on pages 30 and 31, and at the top of these pages are given dates and times which are appropriate.

The scale is the same on all the charts (approximately 25 degrees to the inch), but the overhead stars are plotted as a true map on a conical projection, and are not simple graphs like the main charts.

1L

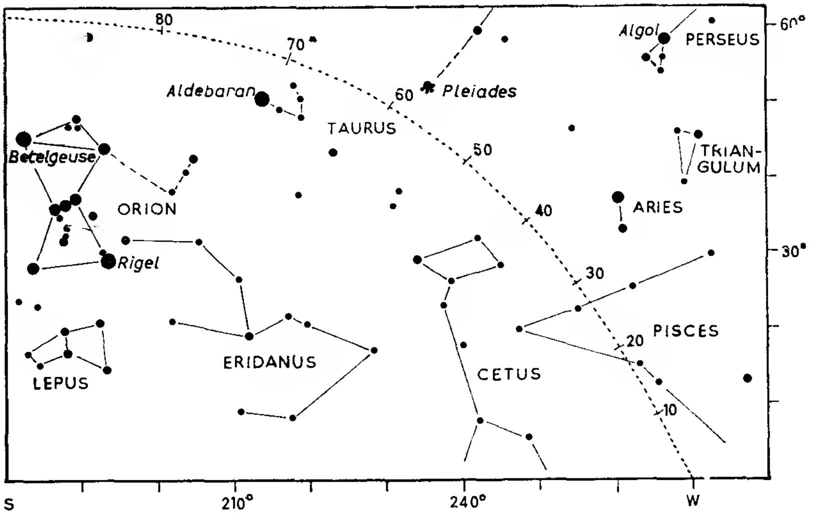
October 6 at 5h	October 21 at 4h
November 6 at 3h	November 21 at 2h
December 6 at 1h	December 21 at midnight
January 6 at 23h	January 21 at 22h
February 6 at 21h	February 21 at 20h

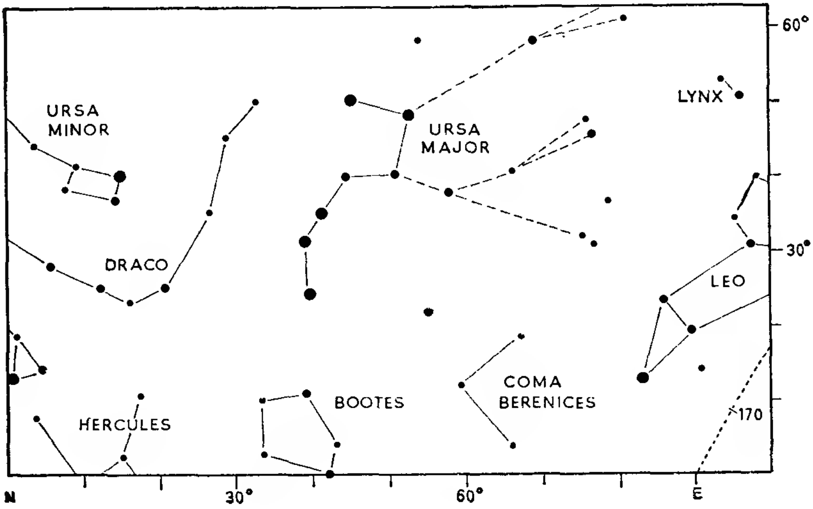




October 6 at 5^h	October 21 at 4^h
November 6 at 3^h	November 21 at 2^h
December 6 at 1^h	December 21 at midnight
January 6 at 23^h	January 21 at 22^h
February 6 at 21^h	February 21 at 20^h

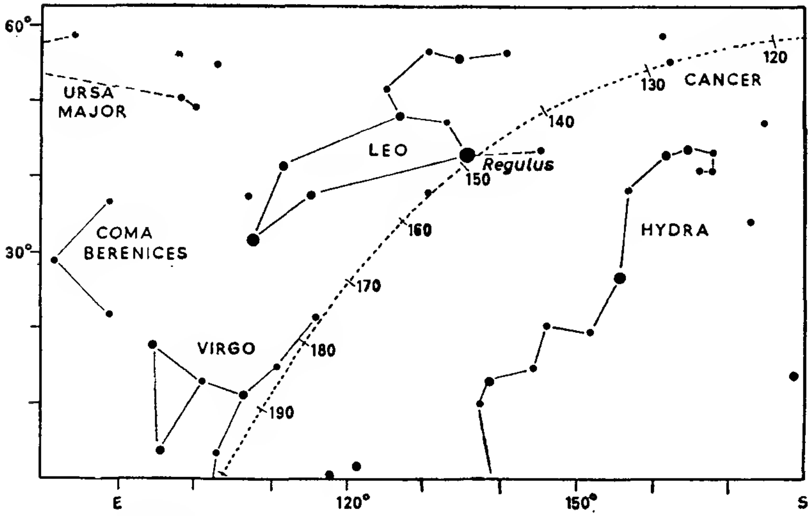
1R

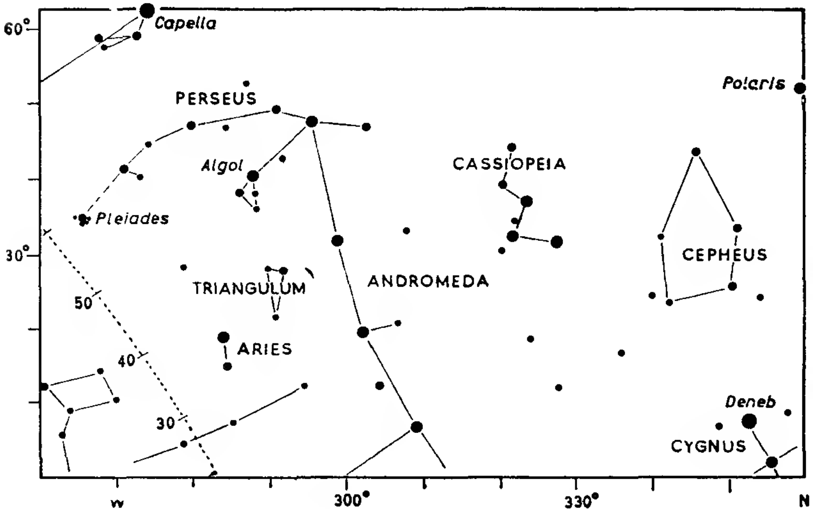




2L

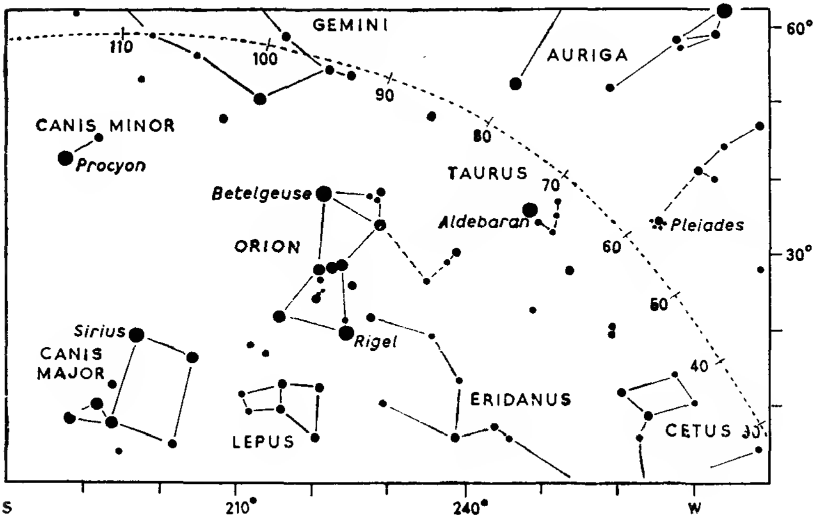
November 6 at 5^{h}	November 21 at 4^{h}
December 6 at 3^{h}	December 21 at 2^{h}
January 6 at 1^{h}	January 21 at midnight
February 6 at 23^{h}	February 21 at 22^{h}
March 6 at 21^{h}	March 21 at 20^{h}

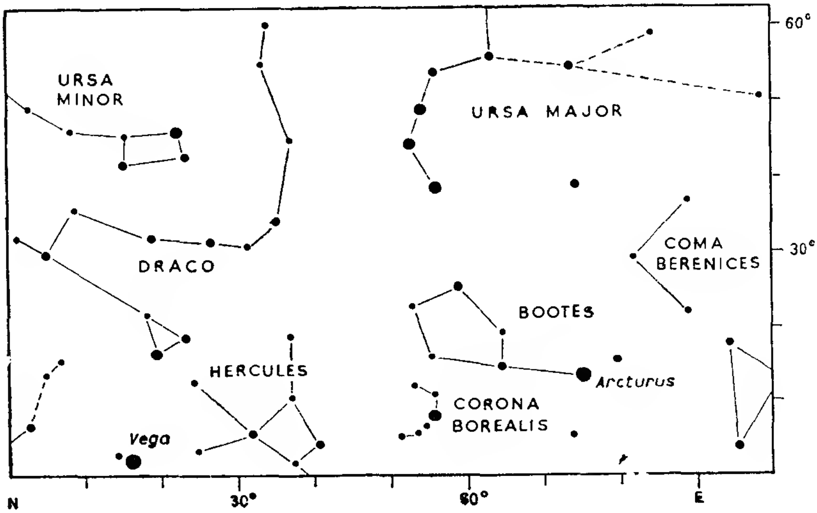




November 6 at 5^h	November 21 at 4^h
December 6 at 3^h	December 21 at 2^h
January 6 at 1^h	January 21 at midnight
February 6 at 23^h	February 21 at 22^h
March 6 at 21^h	March 21 at 20^h

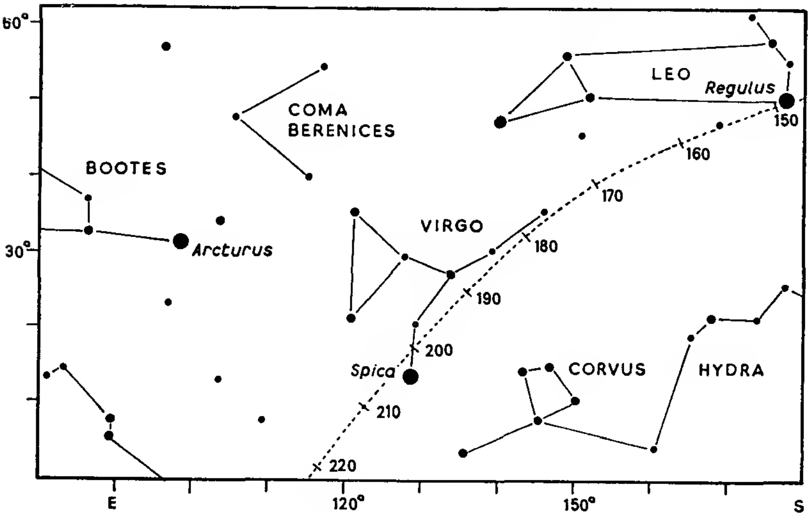
2R

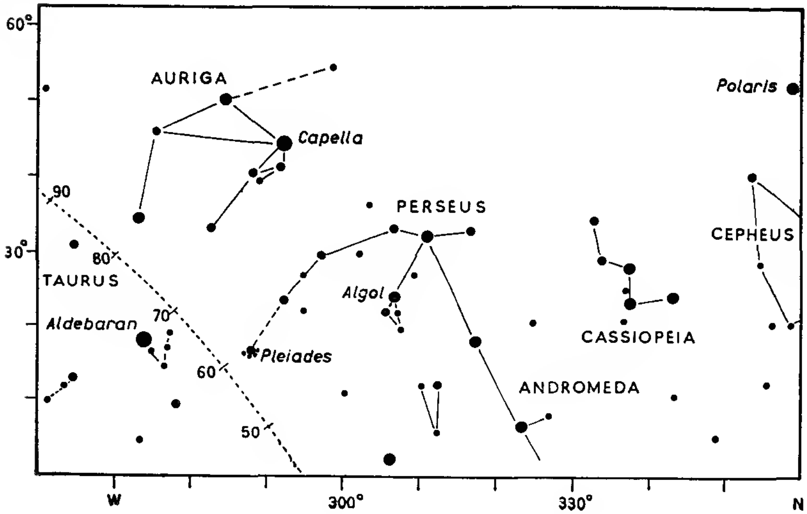




3L

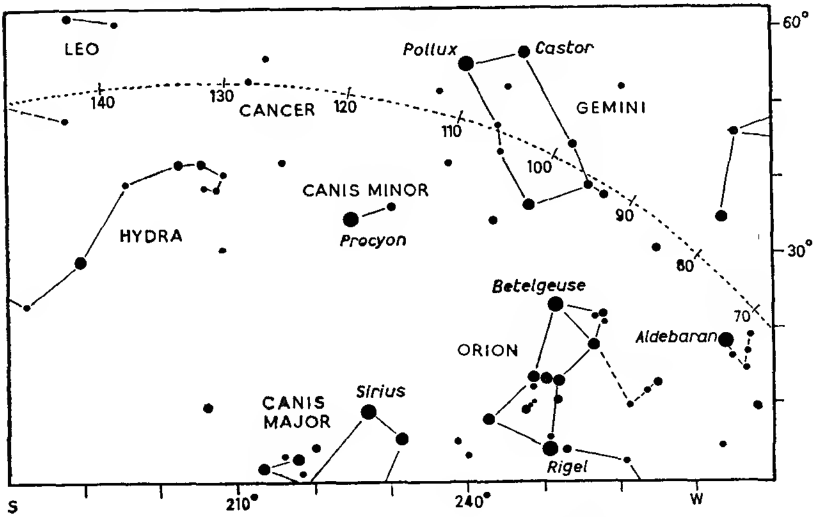
December 6 at 5h	December 21 at 4h
January 6 at 3h	January 21 at 2h
February 6 at 1h	February 21 at midnight
March 6 at 23h	March 21 at 22h
April 6 at 21h	April 21 at 20h

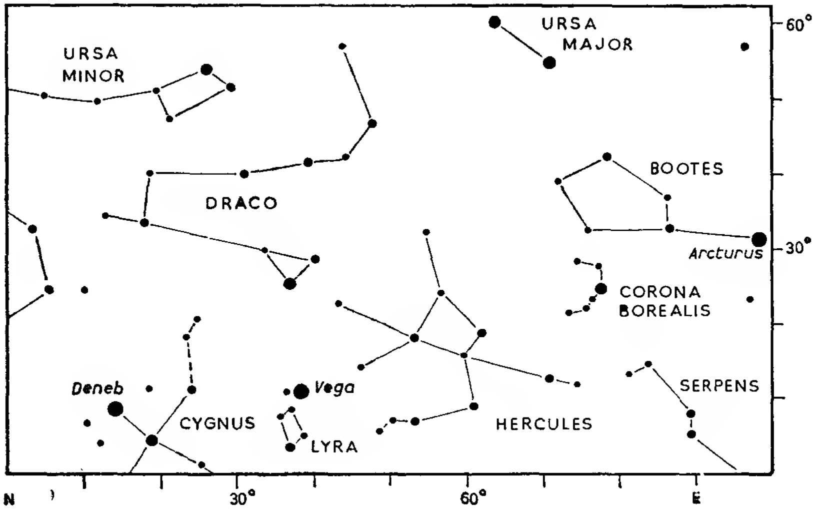




December 6 at 5^h	December 21 at 4^h
January 6 at 3^h	January 21 at 2^h
February 6 at 1^h	February 21 at midnight
March 6 at 23^h	March 21 at 22^h
April 6 at 21^h	April 21 at 20^h

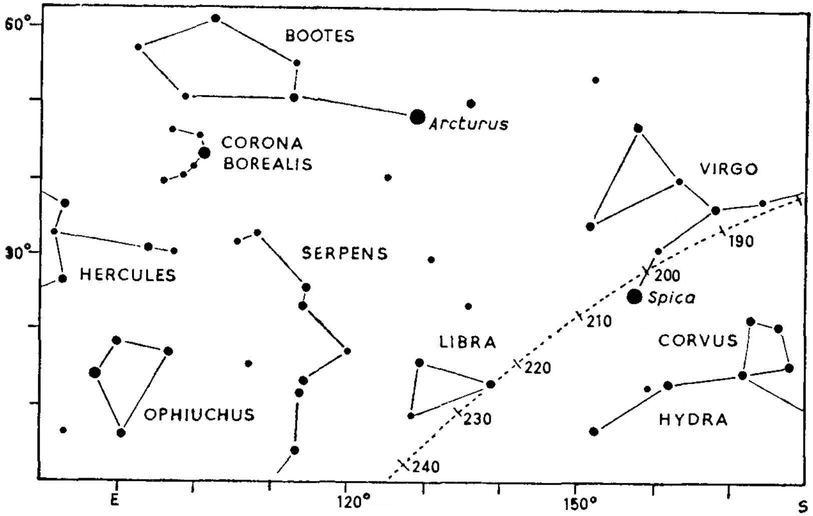
3R

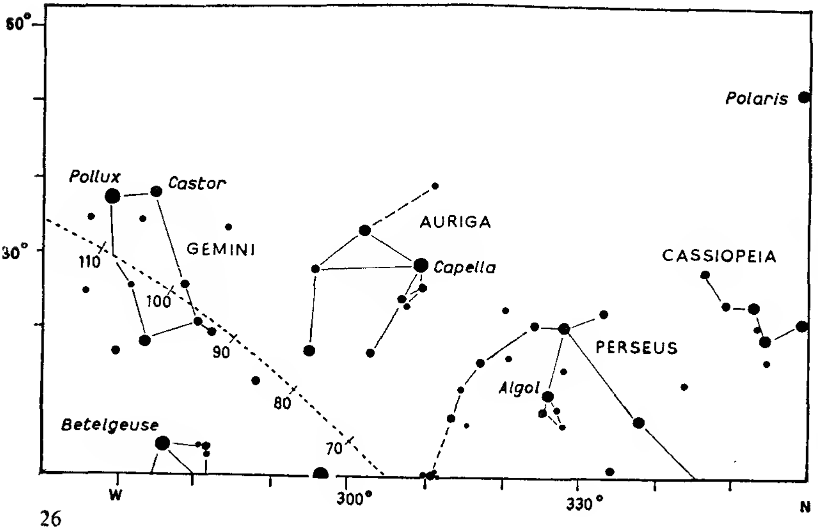




4L

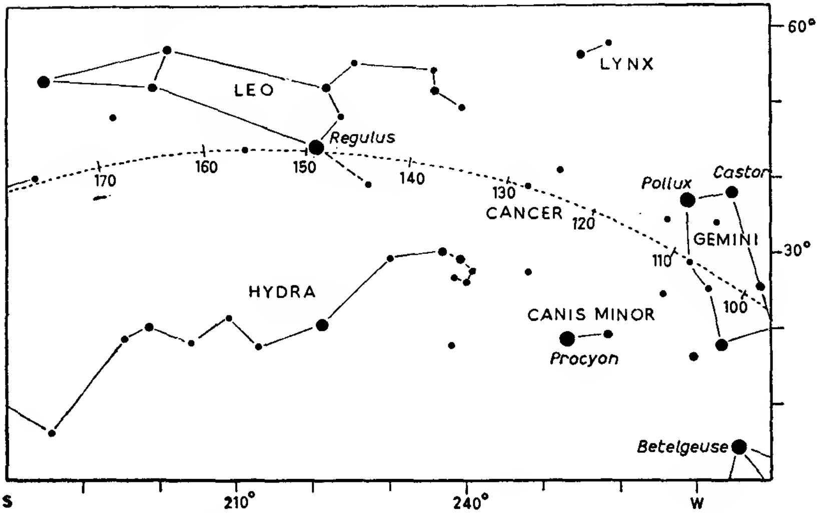
January 6 at 5^h	January 21 at 4^h
February 6 at 3^h	February 21 at 2^h
March 6 at 1^h	March 21 at midnight
April 6 at 23^h	April 21 at 22^h
May 6 at 21^h	May 21 at 20^h

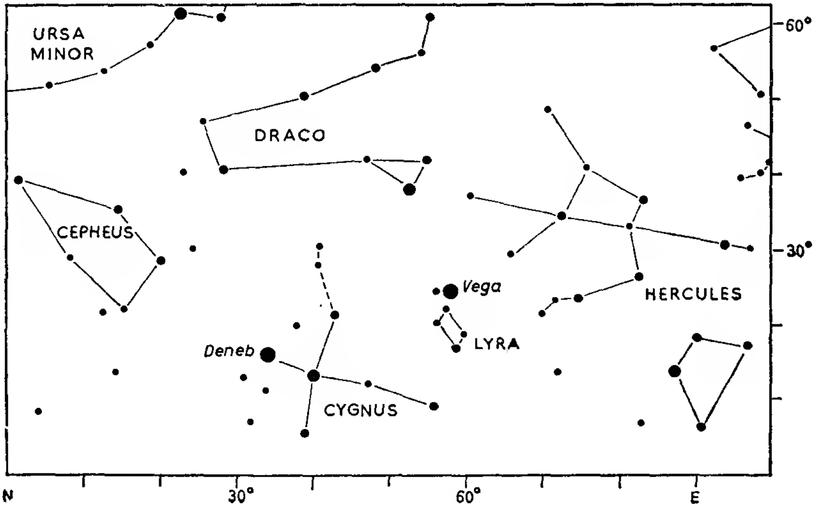




January 6 at	5^h	January 21 at	4^h
February 6 at	3^h	February 21 at	2^h
March 6 at	1^h	March 21 at	midnight
April 6 at	23^h	April 21 at	22^h
May 6 at	21^h	May 21 at	20^h

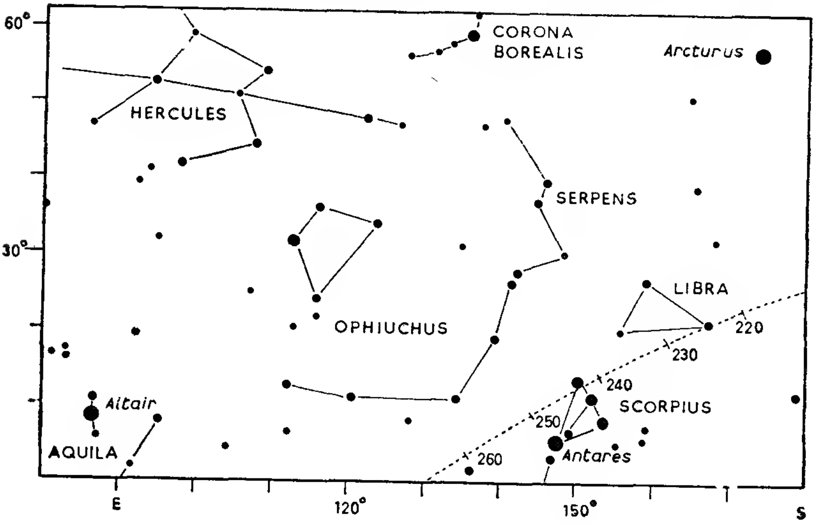
4R

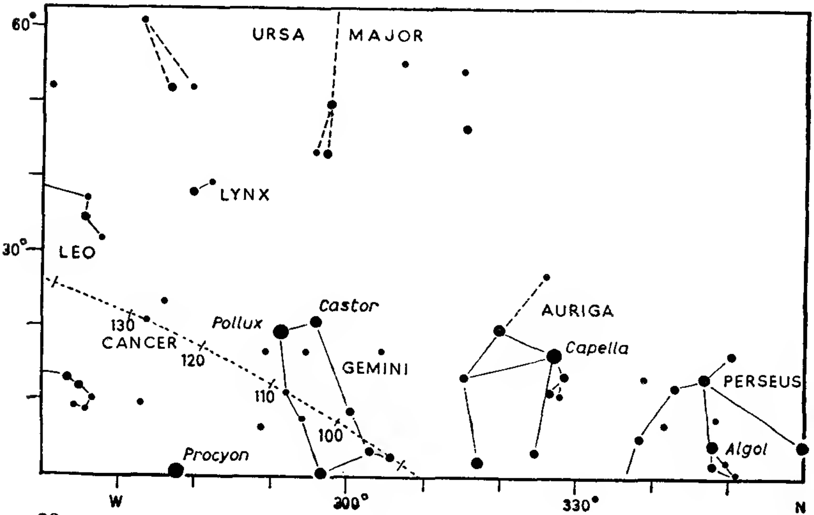




5L

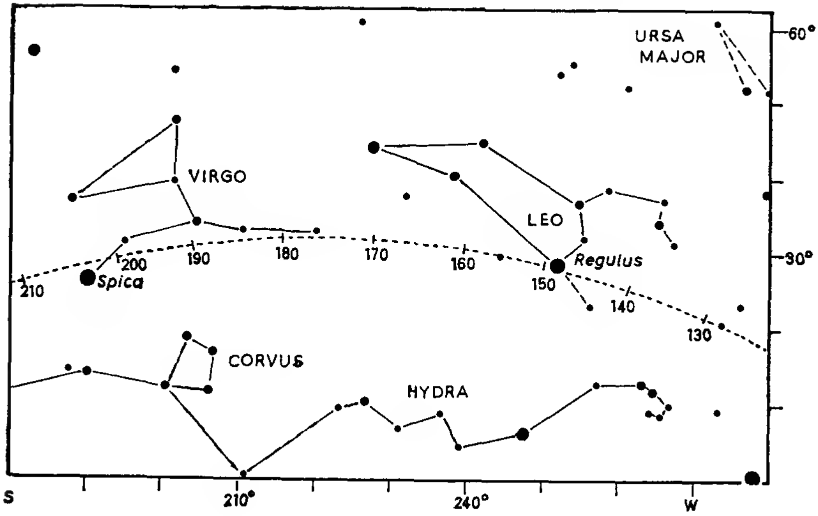
January 6 at	7h	January 21 at	6h
February 6 at	5h	February 21 at	4h
March 6 at	3h	March 21 at	2h
April 6 at	1h	April 21 at	midnight
May 6 at	23h	May 21 at	22h

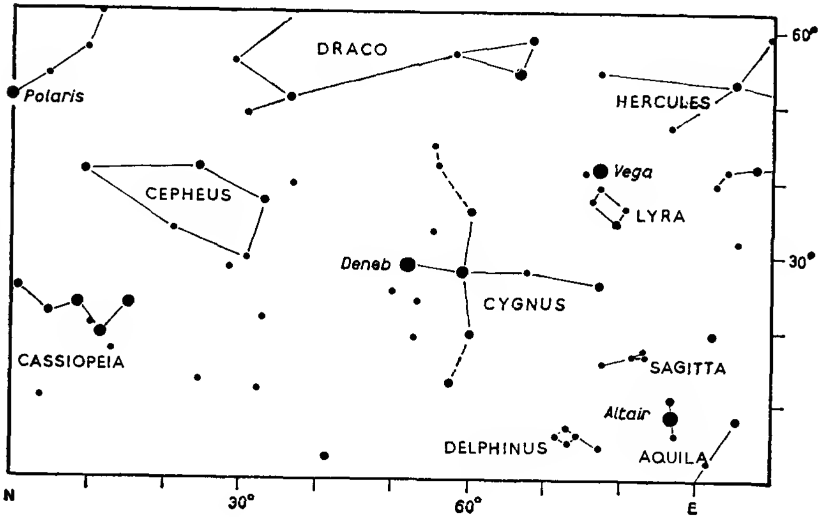




January 6 at 7^h	January 21 at 6^h
February 6 at 5^h	February 21 at 4^h
March 6 at 3^h	March 21 at 2^h
April 6 at 1^h	April 21 at midnight
May 6 at 23^h	May 21 at 22^h

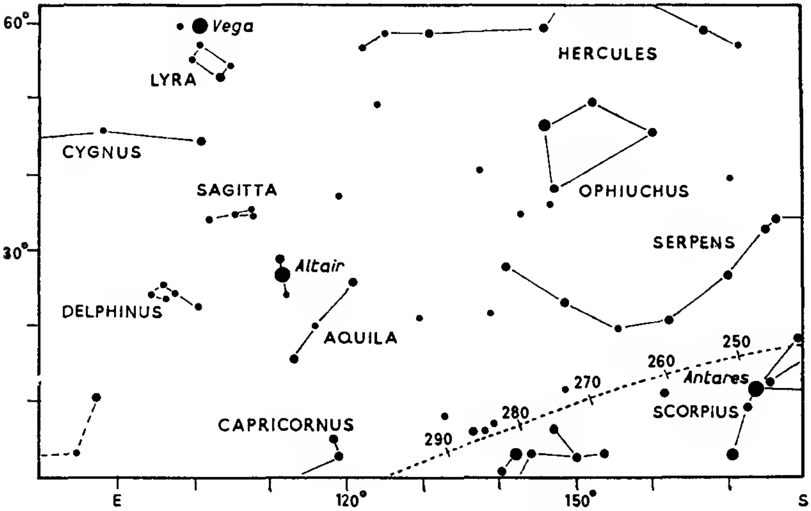
5R

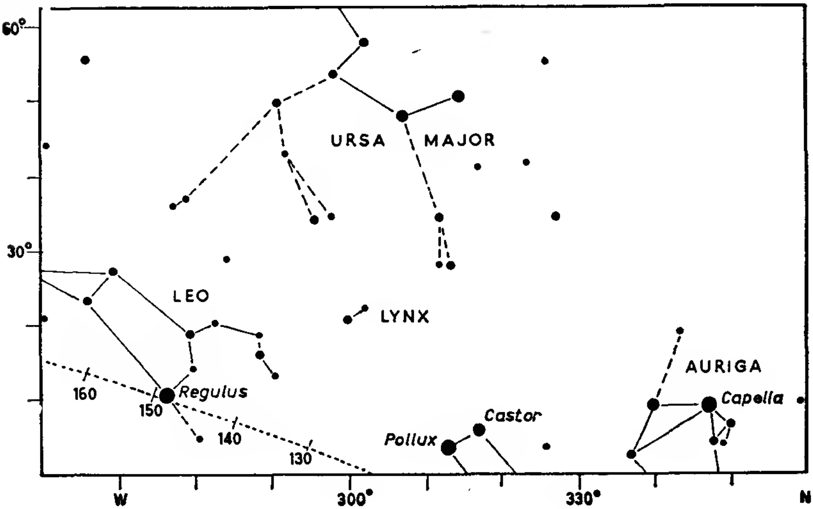




6L

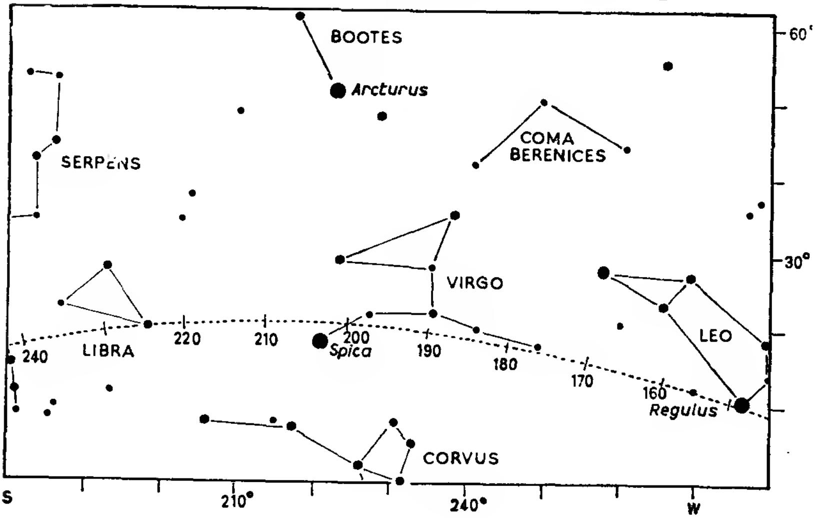
March 6 at 5^h March 21 at 4^h
April 6 at 3^h April 21 at 2^h
May 6 at 1^h May 21 at midnight
June 6 at 23^h June 21 at 22^h
July 6 at 21^h July 21 at 20^h

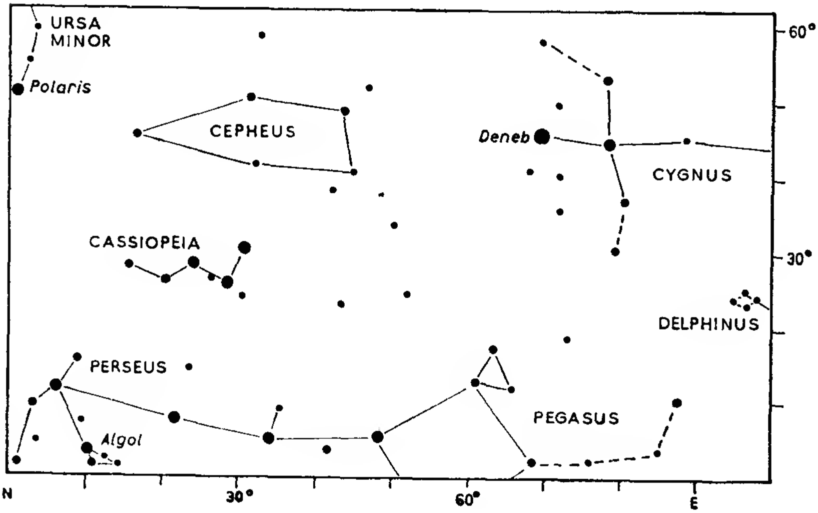




March 6 at 5h	March 21 at 4h
April 6 at 3h	April 21 at 2h
May 6 at 1h	May 21 at midnight
June 6 at 23h	June 21 at 22h
July 6 at 21h	July 21 at 20h

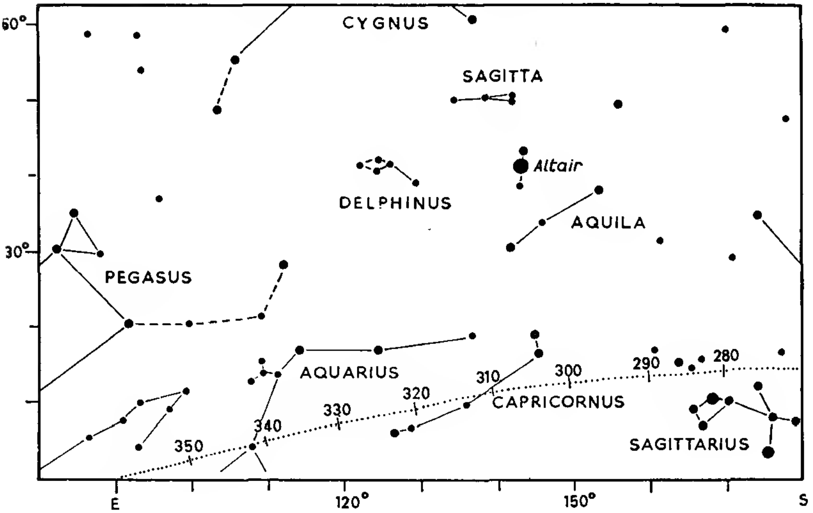
6R

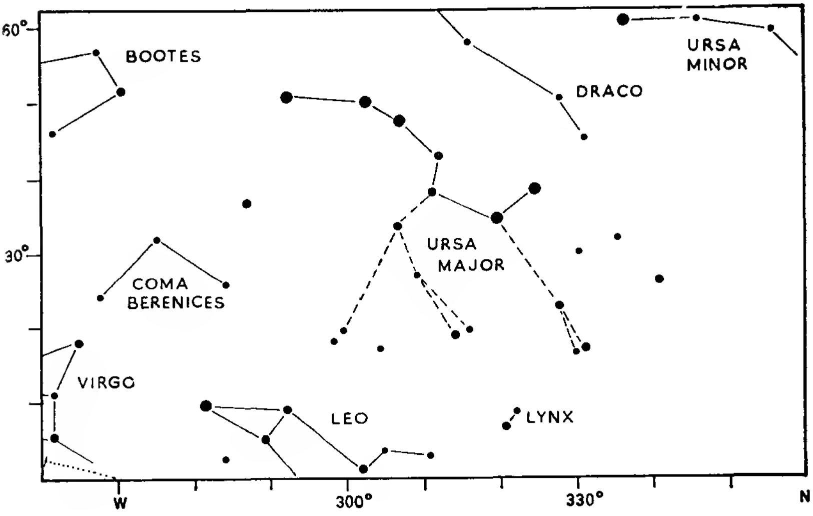




7L

May 6 at	3^h	May 21 at	2^h
June 6 at	1^h	June 21 at	midnight
July 6 at	23^h	July 21 at	22^h
August 6 at	21^h	August 21 at	20^h
September 6 at	19^h	September 21 at	18^h

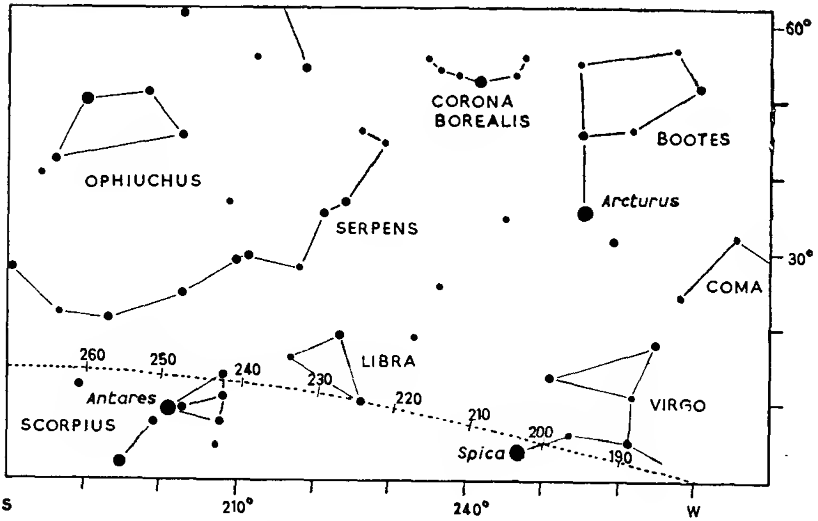


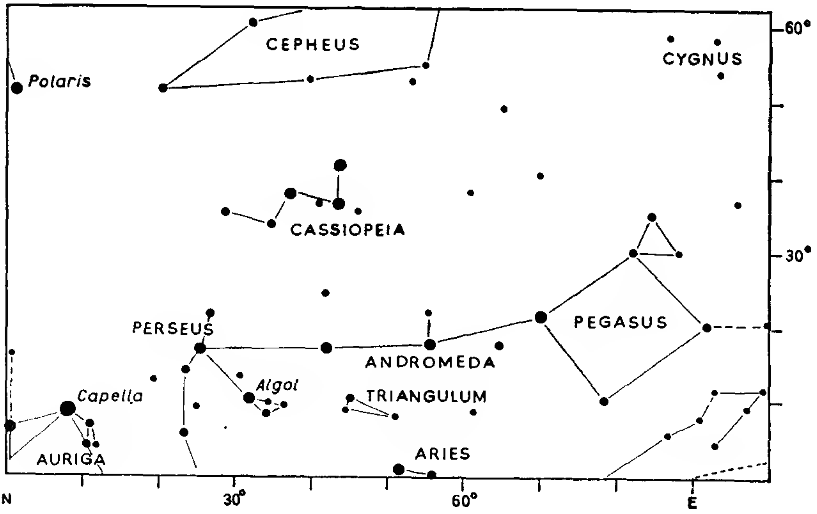


May 6 at 3^{h}
June 6 at 1^{h}
July 6 at 23^{h}
August 6 at 21^{h}
September 6 at 19^{h}

May 21 at 2^{h}
June 21 at midnight
July 21 at 22^{h}
August 21 at 20^{h}
September 21 at 18^{h}

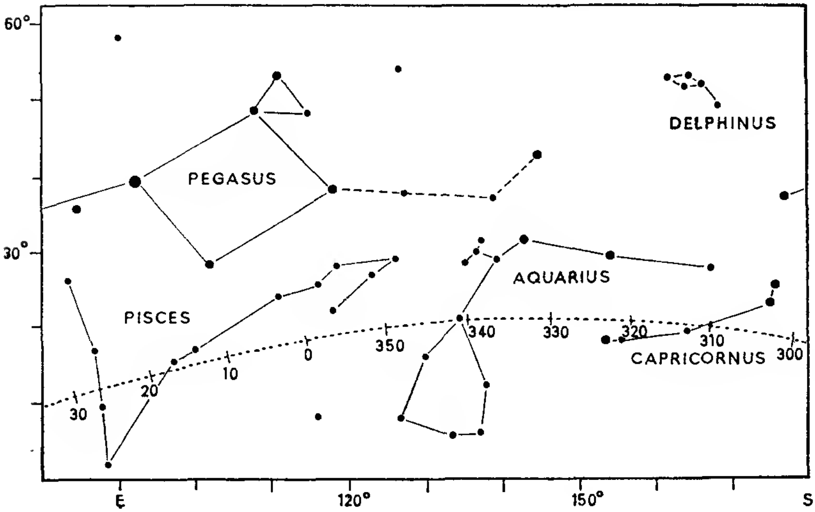
7R

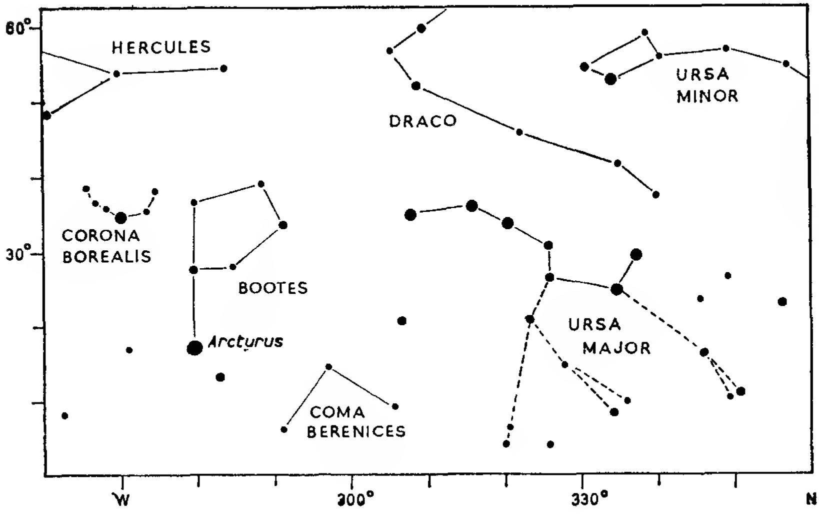




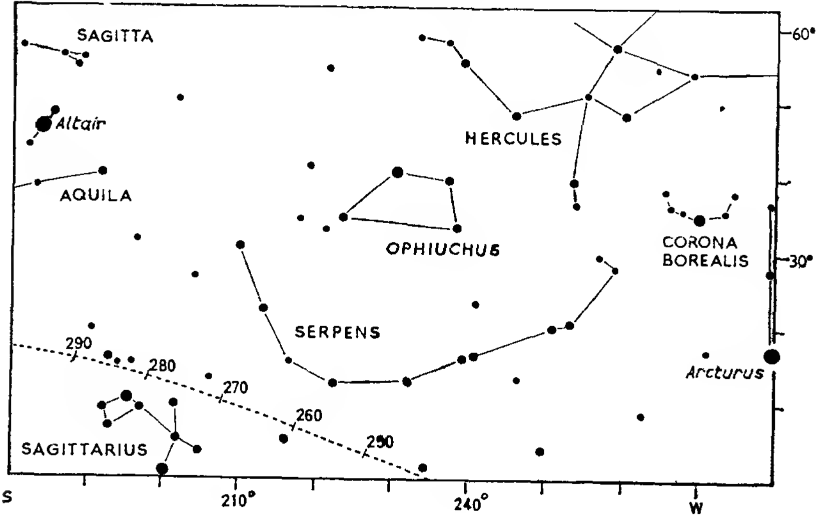
8L

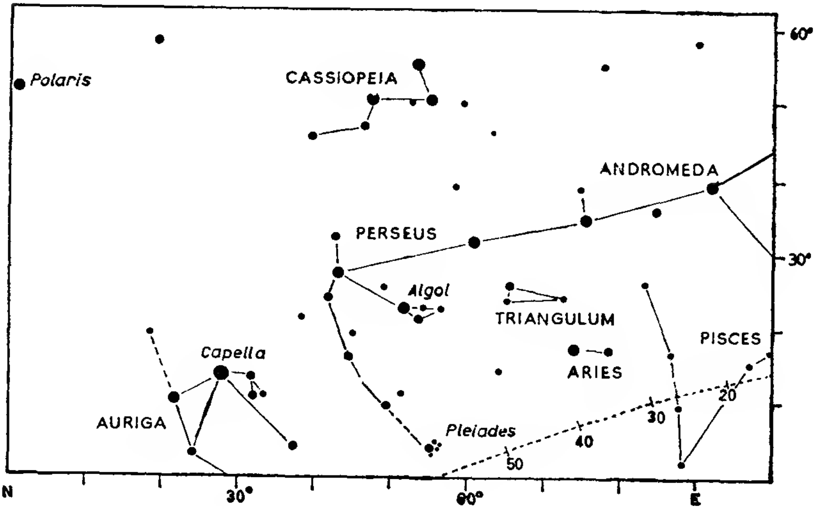
July 6 at 1h — July 21 at midnight
August 6 at 23h — August 21 at 22h
September 6 at 21h — September 21 at 20h
October 6 at 19h — October 21 at 18h
November 6 at 17h — November 21 at 16h





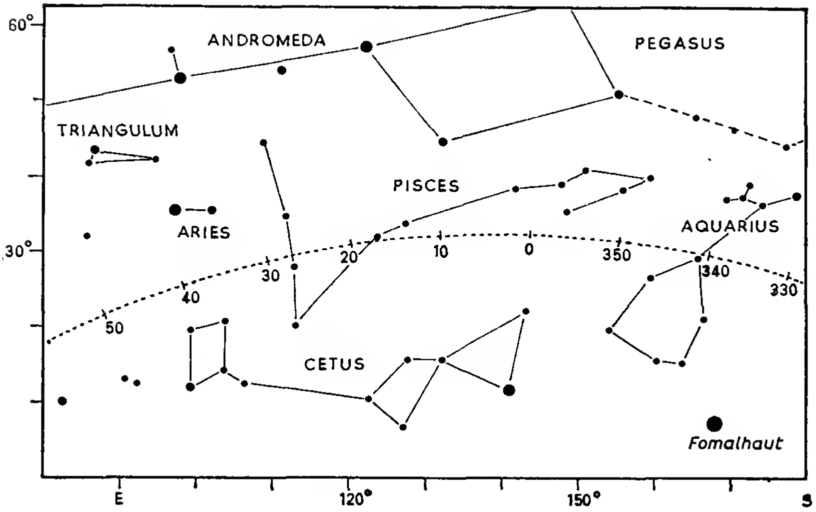
July 6 at 1^h	July 21 at midnight	**8R**
August 6 at 23^h	August 21 at 22^h	
September 6 at 21^h	September 21 at 20^h	
October 6 at 19^h	October 21 at 18^h	
November 6 at 17^h	November 21 at 16^h	

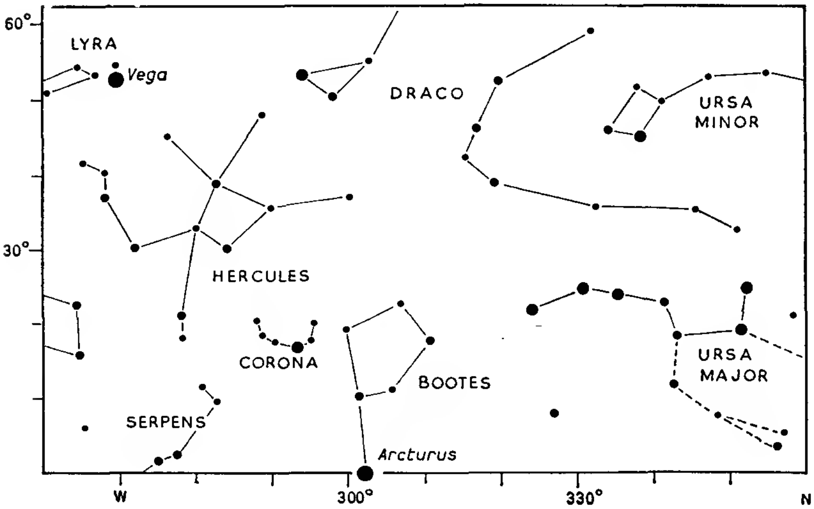




9L

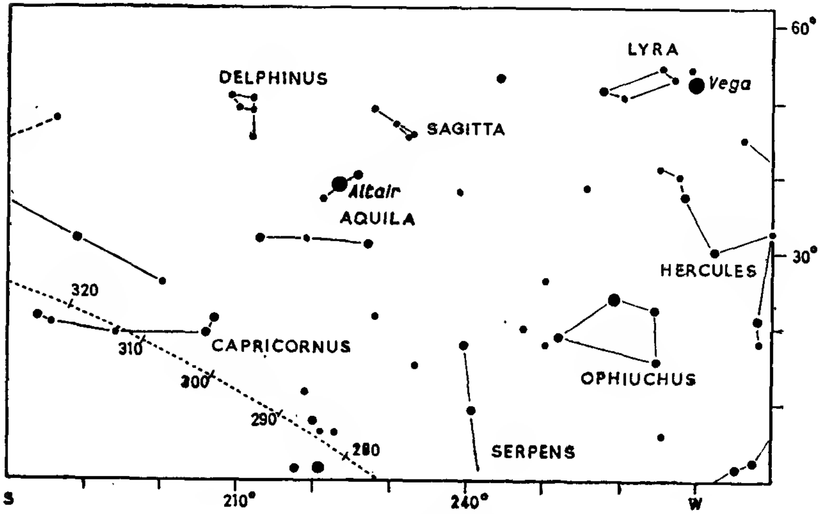
August 6 at 1h	August 21 at midnight
September 6 at 23h	September 21 at 22h
October 6 at 21h	October 21 at 20h
November 6 at 19h	November 21 at 18h
December 6 at 17h	December 21 at 16h

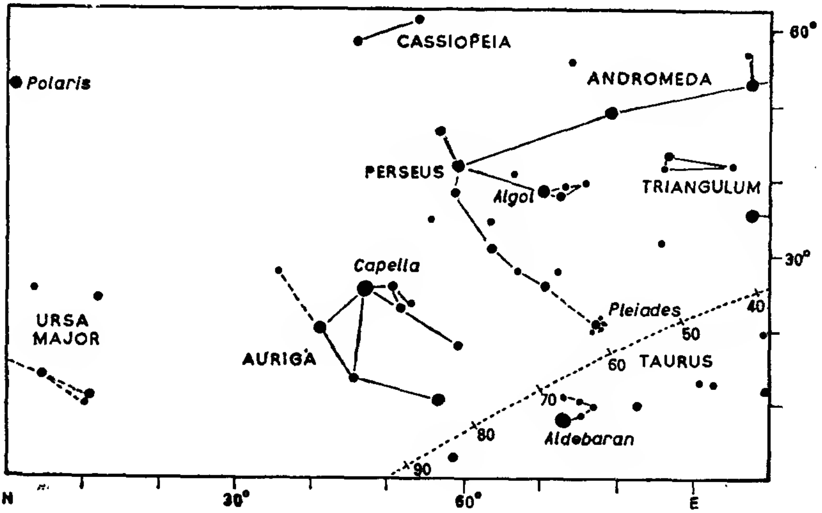




August 6 at 1^h	August 21 at midnight
September 6 at 23^h	September 21 at 22^h
October 6 at 21^h	October 21 at 20^h
November 6 at 19^h	November 21 at 18^h
December 6 at 17^h	December 21 at 16^h

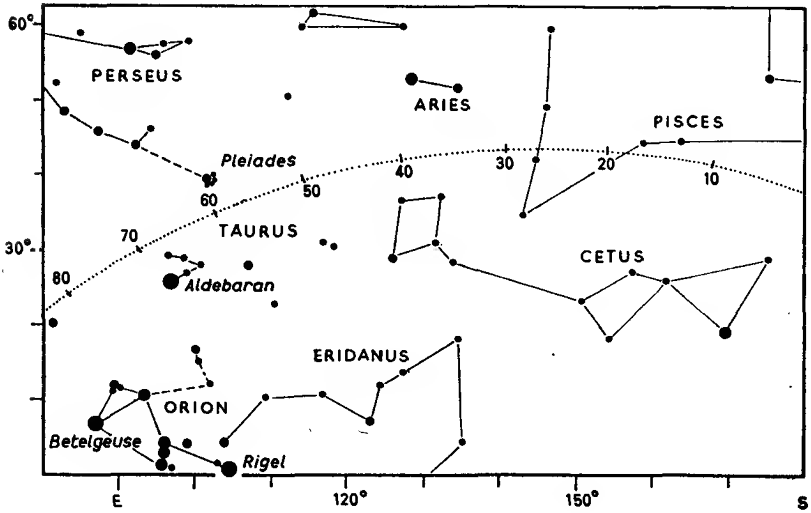
9R

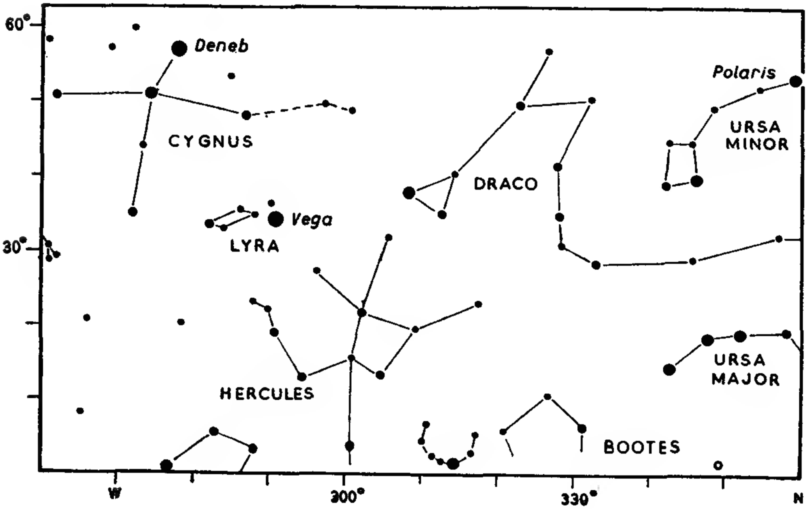




10L

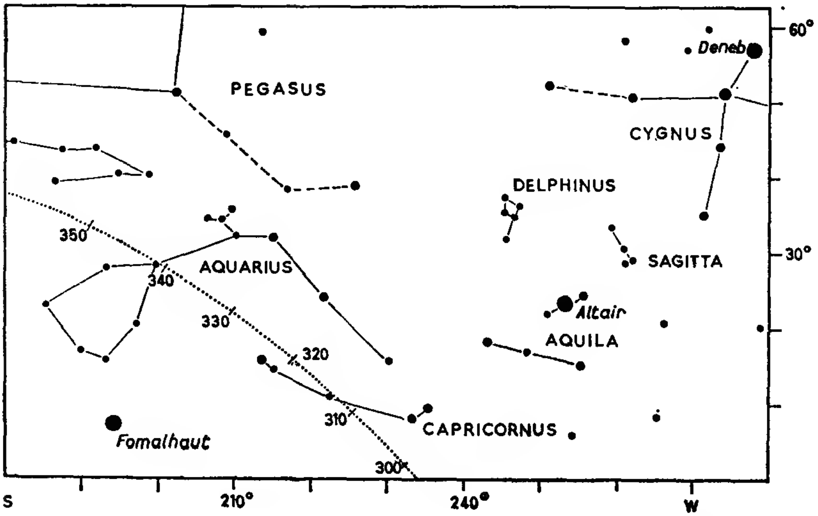
August 6 at 3^h	August 21 at 2^h
September 6 at 1^h	September 21 at midnight
October 6 at 23^h	October 21 at 22^h
November 6 at 21^h	November 21 at 20^h
December 6 at 19^h	December 21 at 18^h

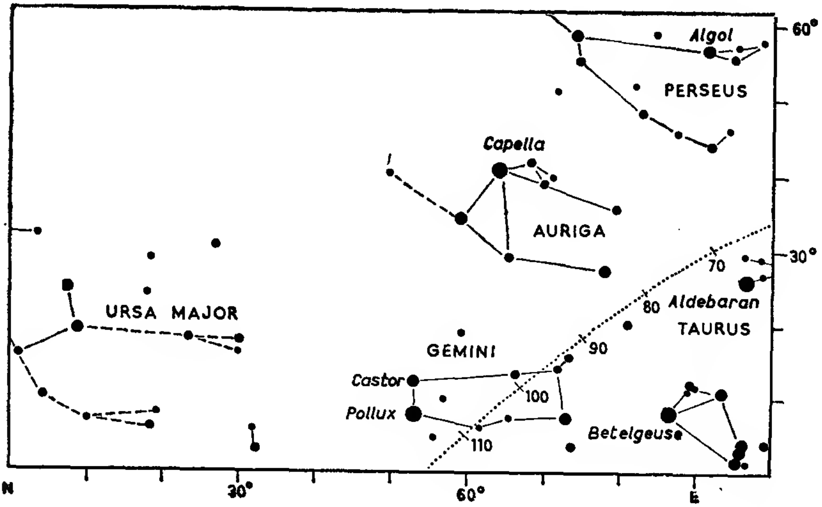




August 6 at 3h	August 21 at 2h
September 6 at 1h	September 21 at midnight
October 6 at 23h	October 21 at 22h
November 6 at 21h	November 21 at 20h
December 6 at 19h	December 21 at 18h

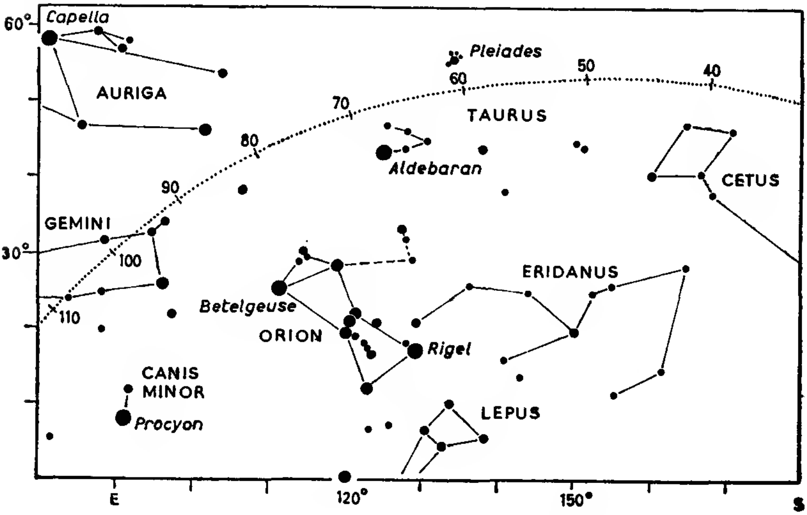
10R

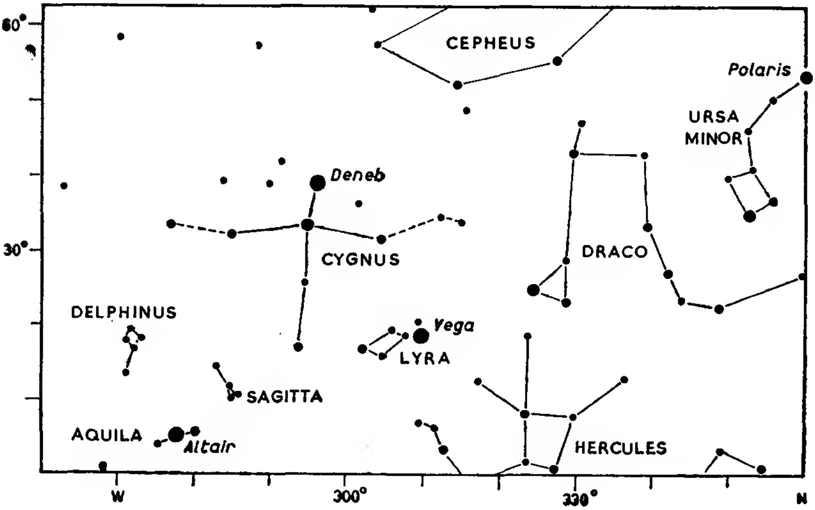




11L

September 6 at 3^h	September 21 at 2^h
October 6 at 1^h	October 21 at midnight
November 6 at 23^h	November 21 at 22^h
December 6 at 21^h	December 21 at 20^h
January 6 at 19^h	January 21 at 18^h





September 6 at 3^h September 21 at 2^h
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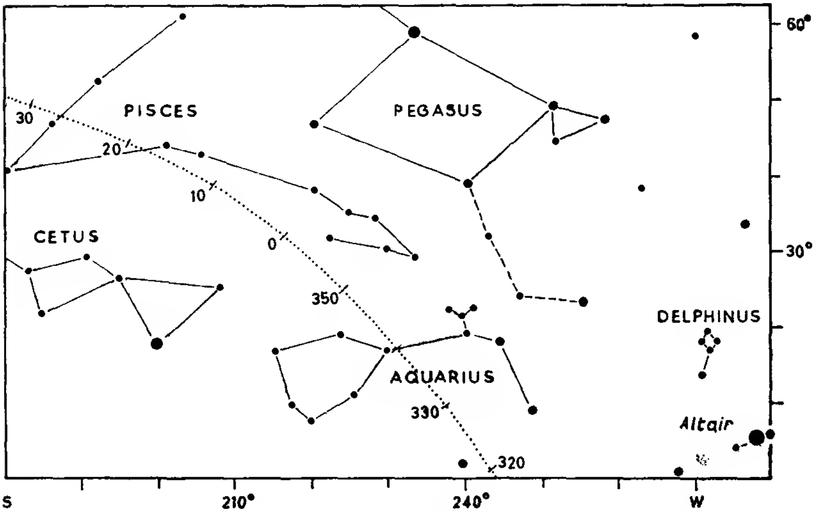
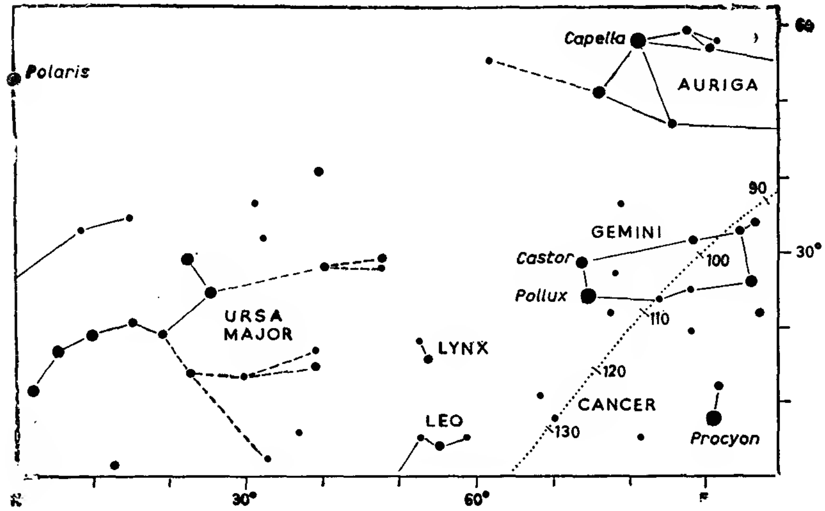
November 6 at 23^h November 21 at 22^h
December 6 at 21^h December 21 at 20^h
January 6 at 19^h January 21 at 18^h

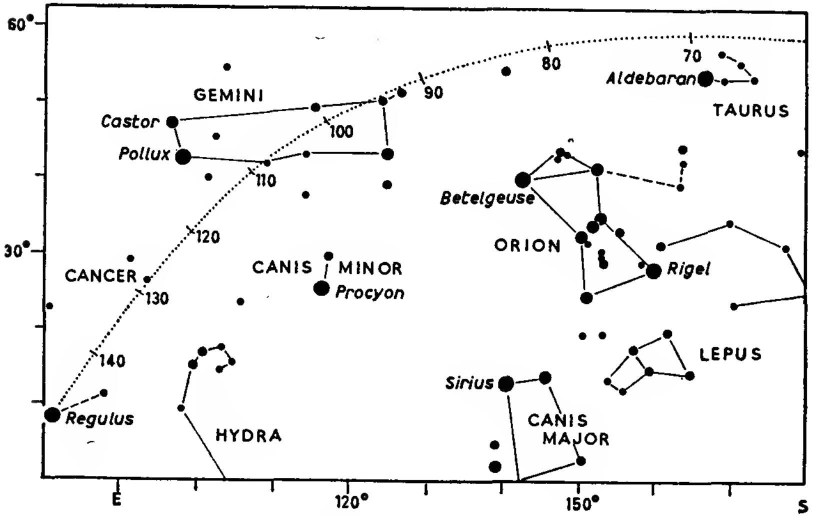
11R

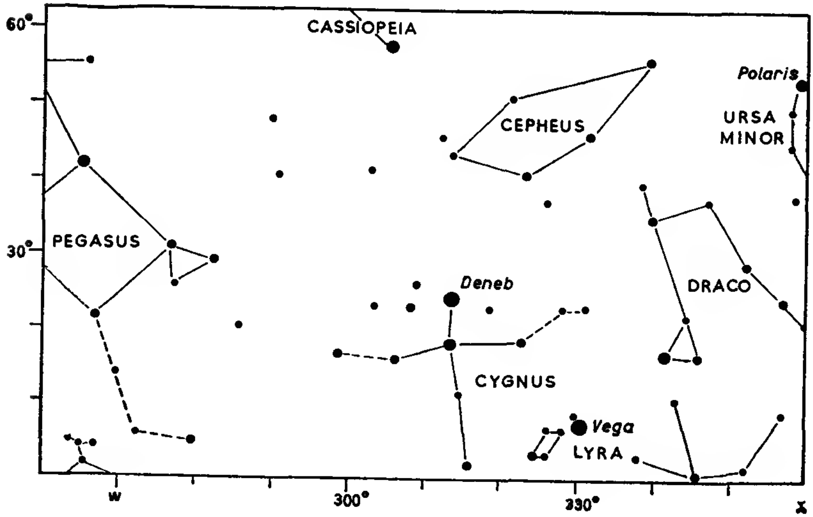




12L

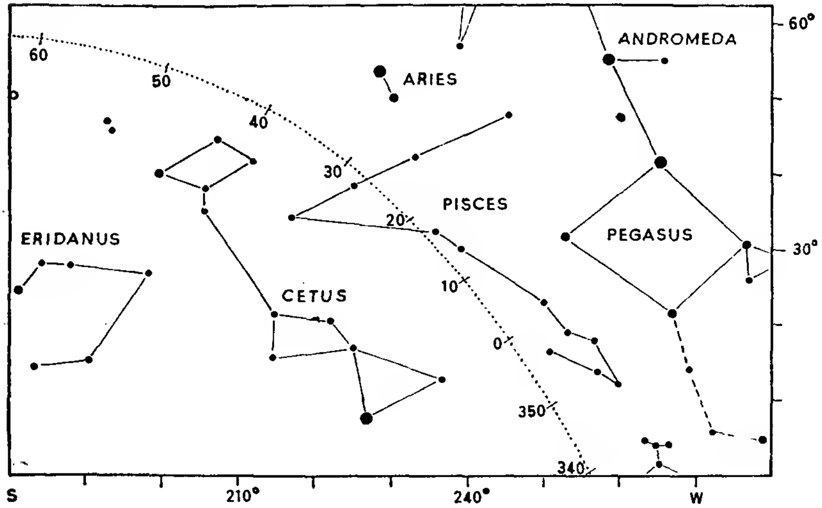
October 6 at 3^h	October 21 at 2^h
November 6 at 1^h	November 21 at midnight
December 6 at 23^h	December 21 at 22^h
January 6 at 21^h	January 21 at 20^h
February 6 at 19^h	February 21 at 18^h

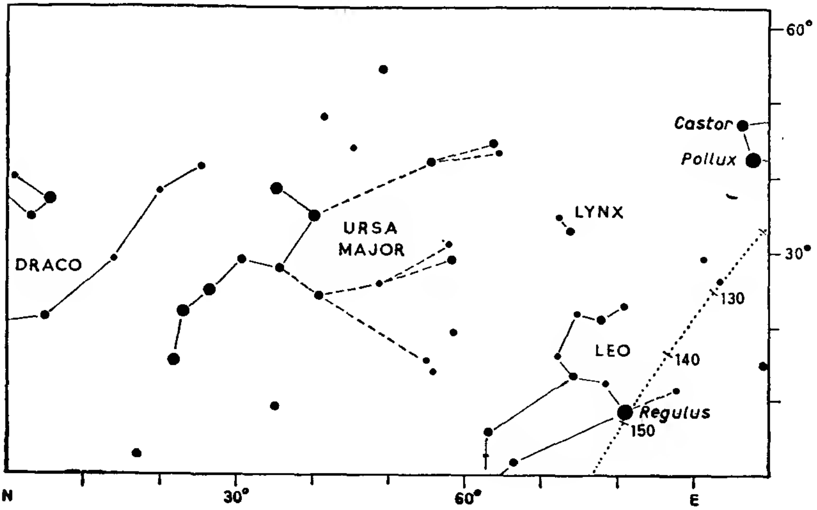


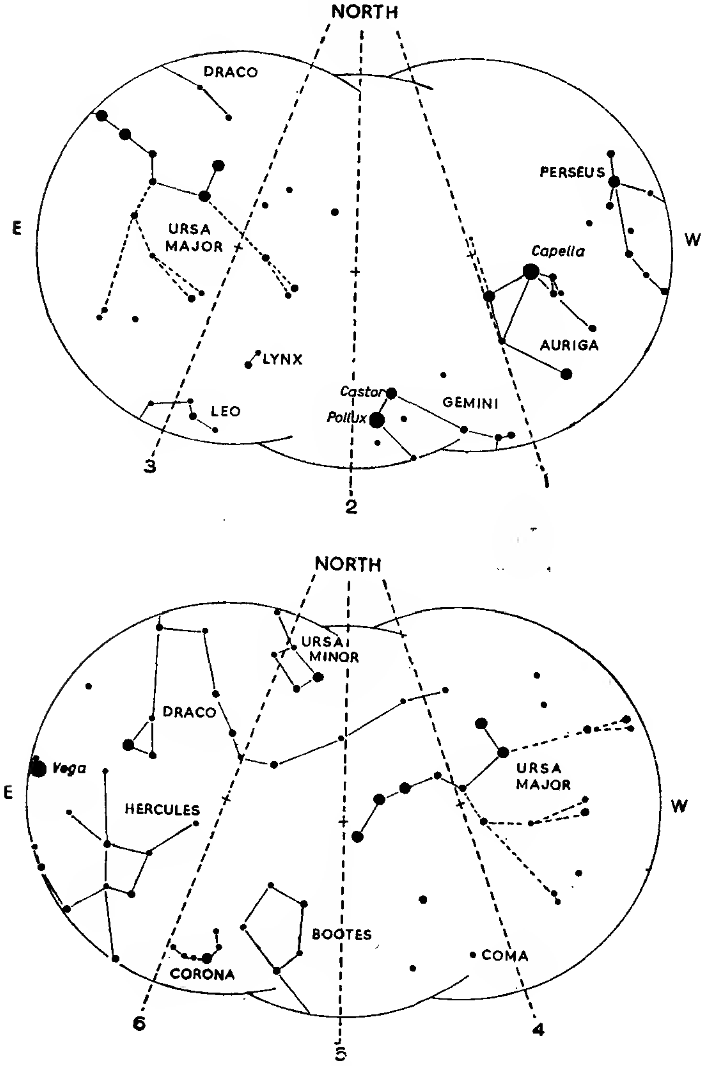


October 6 at 3^h	October 21 at 2^h
November 6 at 1^h	November 21 at midnight
December 6 at 23^h	December 21 at 22^h
January 6 at 21^h	January 21 at 20^h
February 6 at 19^h	February 21 at 18^h

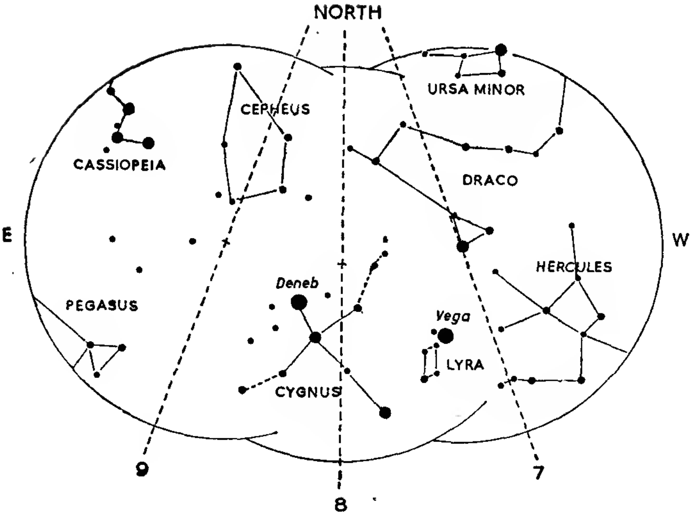
12R

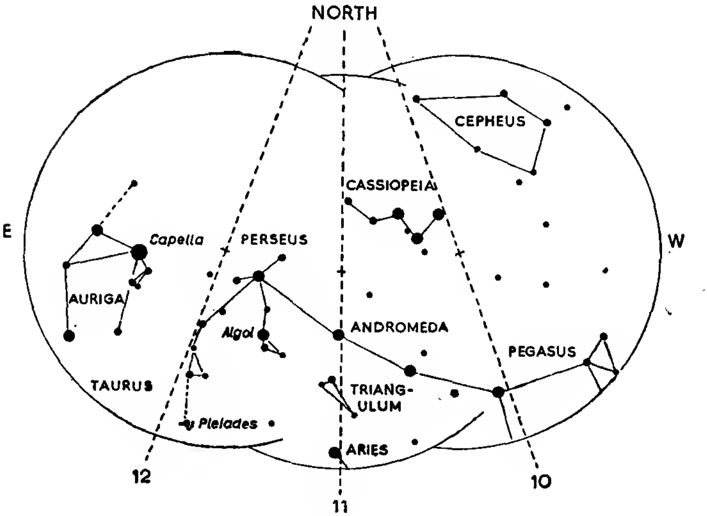






Overhead stars





Overhead stars

The Planets in 1973

DATE		*Venus*	*Mars*	*Jupiter*	*Saturn*	*Uranus*	*Neptune*
January	6	263°	244°	289°	75°	203°	247°
	21	282	255	292	74	203	247
February	6	302	266	296	74	203	247
	21	321	276	300	74	203	248
March	6	337	285	302	74	203	248
	21	356	296	305	75	202	248
April	6	16	307	308	76	202	248
	21	34	318	310	78	201	247
May	6	52	329	311	79	200	247
	21	71	340	312	81	200	247
June	6	90	351	312	83	199	246
	21	109	1	312	85	199	246
July	6	127	11	310	87	199	245
	21	146	20	309	89	199	245
August	6	165	28	307	90	200	245
	21	183	35	305	92	200	245
September	6	201	39	303	93	201	245
	21	219	40	303	94	202	245
October	6	236	38	303	95	203	246
	21	253	34	303	95	204	246
November	6	270	28	305	94	205	247
	21	286	26	307	94	206	247
December	6	299	26	309	93	207	248
	21	308	29	312	91	207	248
Conjunction:							
Superior		Apr. 9	—	Jan. 10	June 15	Oct. 17	Nov. 29
Opposition:		—	Oct. 25	July 30	Dec. 23	Apr. 11	May 27

Mercury moves so quickly among the stars that it is not possible to indicate its position on the star charts at a convenient interval. The monthly notes must be consulted for the best times at which the planet may be seen.

The positions of the other planets are given in the table on the opposite page. This gives the apparent longitudes on dates which correspond to those of the star charts, and the position of the planet may at once be found near the ecliptic at the given longitude.

Examples:

(1) *What are the two brightest planets seen low in the south-west at* 18*h. on* 25 *December?*
Star chart 10R shows the south-western sky at this time, and the longitudes of the planets are seen to be about 310°. The table opposite gives Venus and Jupiter in this part of the ecliptic, Venus being to the west of Jupiter.

(2) *Where may Saturn be found on the night of* 20 *March?*
From the table opposite the longitude of Saturn at this time is found to be 75°. This part of the ecliptic is shown on star charts 2R and 3R, and Saturn will be seen above Aldebaran in the west at about 21h. The planet sets (chart 4L) north of west at midnight.

The Planets and the Ecliptic

The paths of the planets about the Sun all lie close to the plane of the ecliptic, which is marked for us in the sky by the apparent path of the Sun among the stars, and is shown on the star charts by a broken line. The Moon and planets will always be found close to this line, never departing from it by more than about 7 degrees. Thus the planets are most favourably placed for observation when the ecliptic is well displayed, and this means that it should be as high in the sky as possible. This avoids the difficulty of finding a clear horizon, and also overcomes the problem of atmospheric absorption, which greatly reduces the light of the stars. Thus a star at an altitude of 10 degrees suffers a loss of 60 per cent of its light, which corresponds to a whole magnitude; at an altitude of only 4 degrees, the loss may amount to two magnitudes.

The position of the ecliptic in the sky is therefore of great importance, and since it is tilted at about 23½ degrees to the equator, it is only at certain times of the day or year that it is displayed to the best advantage. It will be realized that the Sun (and therefore the ecliptic) is at its highest in the sky at noon in midsummer, and at its lowest at noon in midwinter. Allowing for the daily motion of the sky, these times lead to the fact that the ecliptic is highest at midnight in winter, at sunset in the spring, at noon in summer and at sunrise in the autumn. Hence these are the best times to see the planets. Thus, if Venus is an evening star, in the western sky after sunset, it will be seen to best advantage if this occurs in the spring, when the ecliptic is high in the sky and slopes down steeply to the north-west. This means that the planet is not only higher in the sky, but will remain for a much longer period above the horizon. For similar reasons, a morning star will be seen at its best on autumn mornings before sunrise, when the ecliptic is high in the east. The outer planets, which can come to opposition and are then in the south at midnight, are best seen when opposition occurs in the winter months. Clearly the summer is the least favourable time to observe the planets, for the ecliptic is always low in the sky on summer nights.

Notes on the Planets in the monthly diagrams

The following general notes on observing the planets are followed by detailed month-by-month accounts of the behaviour of the planets, and of other interesting phenomena. These monthly notes include diagrams of the apparent movements of the planets at favourable times of the year. Additional notes on other astronomical phenomena will be found on the following pages.

The inferior planets, Mercury and Venus, move in smaller orbits than that of the Earth, and so are always seen near the Sun. They are most obvious at the times of greatest angular distance from the Sun (greatest elongation), which may reach 28 degrees for Mercury, or 47 degrees for Venus. They are then seen as evening stars in the western sky after sunset (at eastern elongations) or as morning stars in the eastern sky before sunrise (at western elongations). The succession of phenomena, conjunctions and elongations, always follows the same order, but the intervals between them are not equal. Thus, if either planet is moving round the far side of its orbit its motion will be to the east, in the same direction in which the Sun appears to be moving. It therefore takes much longer for the planet to overtake the Sun – that is, to come to superior conjunction – than it does when moving round to inferior conjunction, between Sun and Earth. The intervals given in the following table are average values; they remain fairly constant in the case of Venus, which travels in an almost circular orbit. In the case of Mercury, however, conditions vary widely because of the great eccentricity and inclination of the planet's orbit.

		Mercury	*Venus*
Inferior conj.	to Elongation West	22 days	72 days
Elongation West	to Superior conj.	36 days	220 days
Superior conj.	to Elongation East	36 days	220 days
Elongation East	to Inferior conj.	22 days	72 days

The greatest brilliancy of Venus always occurs about a month *before* greatest western elongation (as a morning star), or a month *after* greatest eastern elongation (as an evening star). No such rule can be given for Mercury, because its distance from Sun and Earth can vary over a wide range.

Mercury is not likely to be seen unless a clear horizon is available; it is seldom seen as much as 10 degrees above the horizon in the twilight sky. In general, it may be said that the most favourable times for seeing Mercury as an evening star will be in spring, some days before greatest eastern elongation; in autumn it may be seen as a morning star some days after greatest western elongation.

Venus is the brightest of the planets, and may be seen on occasions in broad daylight. Like Mercury, it is alternately a morning and an evening star, and will be highest in the sky when it is a morning star in autumn, or an evening star in spring. Venus is seen to best advantage when it comes to greatest eastern elongation in June; it is then well north of the Sun in the spring months and is a brilliant object in the sunset sky over a long period.

The superior planets, which travel in orbits larger than that of the Earth, differ from Mercury and Venus in that they can be seen opposite the Sun in the sky. The superior planets are morning stars after conjunction with the Sun, rising earlier each day until they come to opposition. They will then be in the south at midnight, and visible all night. After opposition, they are evening stars, setting earlier each evening until they set in the west with the Sun at the next conjunction. The interval between conjunctions or between oppositions is greatest for Mars (over two years). At the time of opposition, the planet is nearest the Earth, and therefore at its brightest. This change in brightness is most noticeable with Mars, whose distance from the Earth can vary considerably; the other superior planets are at such great distances that there is very little change in brightness from one opposition to another. The effect of altitude is, however, of importance, for at a December opposition the planet will be among the stars of Taurus or Gemini, and can then be at an altitude of more than 60 degrees in southern England. At a summer opposition, when the planet is in Sagittarius, it may only rise to about 15 degrees above the southern horizon, and so make a less impressive appearance.

Mars, whose orbit is appreciably eccentric, comes nearest to the Earth at an opposition at the end of August; it may then be brighter even than Jupiter, but rather low in the sky in Aquarius. These favourable oppositions occur every fifteen or seventeen years (1924, 1941, 1956, 1971), but in this country the planet is probably better seen at an opposition in the autumn or winter, when it is higher in the sky. Oppositions of Mars occur at an average interval of 780 days, and during this time the planet makes a complete circuit of the sky.

Jupiter is always a bright planet, and comes to opposition a month later each year, having moved, roughly speaking, from one Zodiacal constellation to the next.

Saturn moves much more slowly than Jupiter, and may remain in the same constellation for several years. The brightness of Saturn depends on the aspect of its rings, as well as on the distance from Earth and Sun. The rings are now open at their widest, and the planet is a brilliant object when at opposition.

Uranus, Neptune and *Pluto* are hardly likely to attract the attention of observers without adequate instruments, but some notes on their present positions in the sky will be found in the March, April and May notes.

Phases of the Moon, 1973

New Moon				*First Quarter*				*Full Moon*				*Last Quarter*			
	d	h	m		d	h	m		d	h	m		d	h	m
Jan.	4	15	42	Jan.	12	05	27	Jan.	18	21	28	Jan.	26	06	05
Feb.	3	09	23	Feb.	10	14	05	Feb.	17	10	07	Feb.	25	03	10
Mar.	5	00	07	Mar.	11	21	26	Mar.	18	23	33	Mar.	26	23	46
Apr.	3	11	45	Apr.	10	04	28	Apr.	17	13	51	Apr.	25	17	59
May	2	20	55	May	9	12	07	May	17	04	58	May	25	08	40
June	1	04	34	June	7	21	11	June	15	20	35	June	23	19	45
June	30	11	39	July	7	08	26	July	15	11	56	July	23	03	58
July	29	18	59	Aug.	5	22	27	Aug.	14	02	17	Aug.	21	10	22
Aug.	28	03	25	Sept.	4	15	22	Sept.	12	15	16	Sept.	19	16	11
Sept.	26	13	54	Oct.	4	10	32	Oct.	12	03	09	Oct.	18	22	33
Oct.	26	03	17	Nov.	3	06	29	Nov.	10	14	27	Nov.	17	06	34
Nov.	24	19	55	Dec.	3	01	29	Dec.	10	01	34	Dec.	16	17	13
Dec.	24	15	07												

All times are G.M.T.

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MONTHLY NOTES, 1973

January

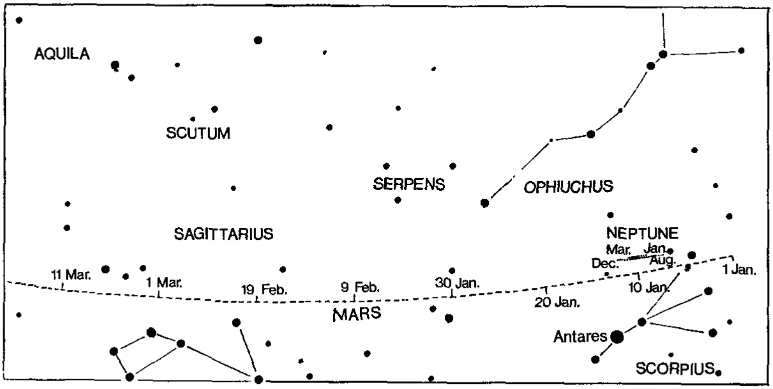
New Moon: 4 January *Full Moon*: 18 January

Earth is at perihelion (nearest to the Sun) on 2 January, the distance being then about 91,400,000 miles (147,100,000 km).

Mercury is in superior conjunction on 28 January, and will not be visible during the month.

Venus is a morning star, rising about an hour before the Sun at the beginning of the year. It is now moving round the far side of its orbit and its elongation from the Sun is decreasing. There will be little chance to see the planet by the end of the month, and in general Venus will not be a very conspicuous object during 1973.

Mars is also a morning star, rising about three hours before the Sun. It is moving rapidly direct in Scorpius, and is not yet a very brilliant object (magnitude +1·8 to +1·6). Mars passes about 5 degrees north of Antares (the so-called "rival of Mars") on 12 January, and this gives an opportunity to compare the colours of the two objects, which are of comparable magnitudes (Antares +1·2). In the middle of January Mars passes into Ophiuchus, a constellation which here intrudes into the Zodiac.



Mars (January to March) and Neptune

Jupiter is in conjunction with the Sun on 10 January. After this it becomes a morning star in Sagittarius, but it will be some weeks before it is visible to the naked eye.

Saturn is a bright evening star in Taurus. The planet was at opposition in December last, and is still moving retrograde, growing fainter as its distance increases (magnitude −0·2 to +0·1). It may be found shortly after sunset above the tilted figure of Orion in the east, and to the left of Aldebaran and the Hyades.

An annular eclipse of the Sun on 4 January will be visible only in the southern hemisphere (see notes on page 114).

OPHIUCHUS IN THE ZODIAC

It is always said that there are twelve constellations in the Zodiac: Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpius (or Scorpio), Sagittarius, Capricornus, Aquarius and Pisces. The Sun, the Moon and the bright planets always lie near the ecliptic; indeed, the only principal planet which can move far away from the ecliptic plane is Pluto, whose orbital inclination is 17°. However, there is another constellation which intrudes into the Zodiac for some distance between Scorpius and Sagittarius. This is Ophiuchus, the Serpent-bearer; and for part of this month it actually contains the planet Mars.

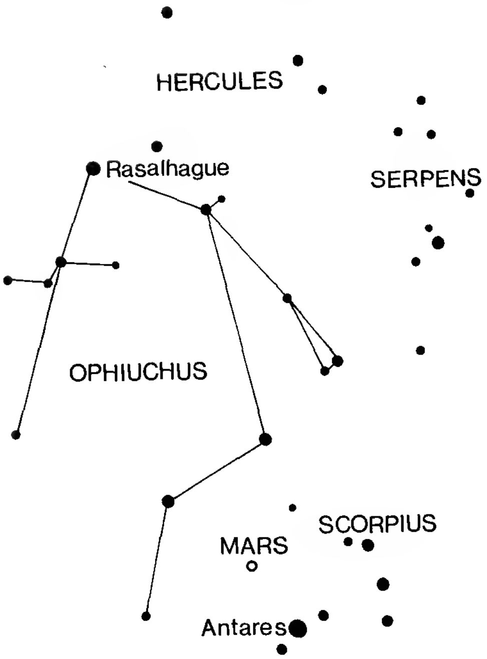
Like the twelve official groups of the Zodiac, Ophiuchus is an ancient constellation; it was given by Ptolemy, the last great astronomer of Classical times, in his "original 48". Moreover, it is much larger in area than some of the Zodiacal constellations – Libra, for instance. It used to be called Serpentarius, a name still found occasionally; mythologically it has been identified with Æsculapius, son of Apollo and Coronis, who became so skilled in the art of medicine that he not only healed the sick but restored the dead to life. According to the old story, this so alarmed Pluto, ruler of the Underworld, that Jupiter or Zeus – the ruler of Olympus – reluctantly killed Æsculapius with a thunderbolt, though afterwards relented sufficiently to place him in the sky!

Though Ophiuchus is large, it is not very striking. Its leading star is Alpha or Rasalhague, of magnitude 2·1, which is rather isolated, and is therefore easy to identify; it is 58 light-years from us, and is of spectral type A5, so that its surface is considerably hotter than that of the Sun. The other stars in Ophiuchus above the third magnitude are Eta or Sabik (2·5), Zeta or Han (2·6), Delta or Yed Prior (2·7) and Beta or Cheleb (2·8), but the constellation has no distinctive shape, and is decidedly barren of interesting telescopic objects. It borders two more large but rather faint groups, Hercules and Serpens.

Astrologers of former years paid scant attention to Ophiuchus, and did not allot it an astrological sign. However, it is true that the faint star Omega Ophiuchi, to the north of Antares in Scorpius, does lie extremely close to the ecliptic – and the neglect can be due only to the fact that a thirteenth Zodiacal constellation did not fit neatly into the astrological cult!

MARS AND ANTARES

Mars, the 'Planet of War', is always distinguished by its strongly red colour. Because of its very variable distance from



the Earth, and its relatively small size (approximately half the diameter of the Earth) its brightness is very changeable. At its best it can outshine any star, and any planet apart from Venus; this will be the case later in 1973. When at its faintest, however, it descends to the second magnitude, and looks very like a star. Unwary observers have often mistaken it for a nova.

This January Mars is still a long way away from us, and is not yet striking, though it still ranks with the brightest stars in the sky apart from the leading few such as Capella and Rigel. As has been noted above, it lies near Antares – and the very name Antares means 'the Rival of Mars', because the colours of the two are superficially very alike. Looking at them as they are seen fairly close together, it requires a conscious mental effort to realize that Mars is one of the smaller planets in the

Solar System, while Antares is a giant sun far superior to ours in both size and luminosity. This will be even harder to credit during the late summer, when Mars will be so spectacular – though by then it will, of course, have moved well away from Antares.

The two objects are well worth looking at this month, though it means getting up early; Antares and Mars can be seen low in the south-east just before dawn.

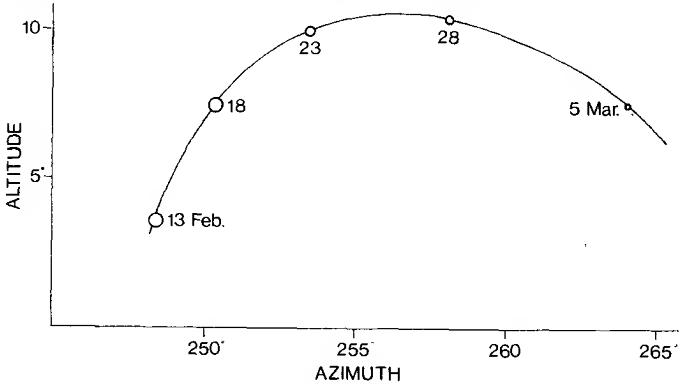
ANTONIE PANNEKOEK

This distinguished Dutch astronomer was born on 2 January 1873 at Vaasen, in Gelderland. He spent much of his life in Amsterdam, becoming Director of the Astronomical Institute there. He is remembered chiefly for his investigations of the solar chromosphere and of the dust-clouds in the Milky Way; he was also the author of many papers and one book dealing with the history of astronomy.

February

New Moon: 3 February *Full Moon*: 17 February

Mercury is at greatest eastern elongation (18°) on February 25, and is then well placed for observation as an evening star in the west after sunset. The diagram shows the changes in altitude and azimuth (true bearing from the north through east, south and west) of Mercury on successive evenings when the Sun is six degrees below the horizon; this will be about half an hour after sunset at this time of year. The changes in brightness are roughly indicated by the size of the circles, and it will be seen that Mercury is brightest before the date of greatest elongation.



Mercury, February 1973

Venus is now setting shortly after the Sun, and there is little likelihood of its being seen.

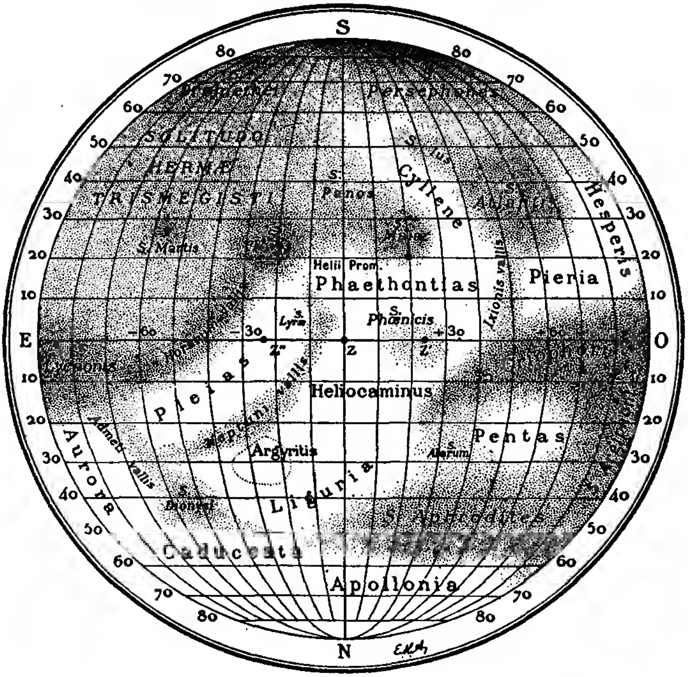
Mars rises about two hours before the Sun, and will be seen in the south just before sunrise. The planet moves into Sagittarius in the first week of February and grows a little brighter (magnitude +1·6 to +1·3). Mars will be seen close to the crescent moon on the morning of 28 February.

Jupiter begins to appear as a morning star at the end of February, when it rises about an hour before the Sun. It will then have moved into Capricornus, and remains in this constellation throughout the year. (Magnitude −1·5).

Saturn is an evening star in Taurus, and sets in the early morning hours. It reaches a stationary point on 13 February some degrees north-east of Aldebaran, and after this date it begins to move direct once again. (Magnitude +0·1 to +0·2).

CRATERS ON MERCURY?

Though Mercury will be at its best this month, and should be easily visible with the naked eye under good conditions (that is to say, absence of artificial lights — and also a clear horizon,



with no low-lying mist), no telescope of ordinary size will show much upon its surface. Generally, all that can be made out is the characteristic phase. Giant instruments will show some markings; the map drawn by Antoniadi forty years ago remains probably the best, since it was made by an expert observer with the aid of the Meudon 33-inch refractor, near Paris. We still use Antoniadi's nomenclature.

How accurate is this map? It is difficult to say. Mercury is excessively hard to study; it is best observed during broad daylight, when both it and the Sun are well above the horizon, but this means using a very large telescope equipped with setting-circles, and the normal amateur-owned instrument is of no use at all. Probably the main dark markings are more or less correctly placed on the map, but this is about as far as we can go as yet.

Fortunately the situation may be dramatically altered by the Venus-Mercury Mariner scheduled for later in 1973. The main object of the experiment is close-range photography of Mercury, and it is worth speculating as to what may be found there. Because of the virtual lack of atmosphere, Earth-type life seems to be out of the question; and neither can we expect clouds, though it is true that Antoniadi recorded 'obscurations' over the planet's surface which he regarded as just as frequent and dense as those of Mars.

In size and mass, Mercury is intermediate between Mars and the Moon. With its diameter of approximately 3000 miles (slightly less, according to the latest estimates) and its escape velocity of 2·6 miles per second, nothing in the way of a dense atmosphere could be expected; and if we discount Antoniadi's 'clouds', as most modern observers tend to do, neither will there be any marked erosion. On the other hand, the alternate heating and chilling of the surface must result in crumbling. We now know that Mercury spins on its axis once in 58½ days, instead of having a captured or synchronous rotation; therefore every part of the planet experiences sunlight at one time or another. The maximum temperature is extremely high, but the night temperature is very low, because there is no atmosphere to retain warmth.

Both the Moon and Mars are cratered. There is still discussion as to the origin of the lunar craters, and both the volcanic and the impact theories have strong supporters. With Mars, there can be little doubt that vulcanism has played the major rôle. The new Mariner should tell us whether Mercury, too, is crater-scarred – and also whether the surface structures are more 'lunar' or more 'Martian'.

It may well be that the surface will be much more fragmented and levelled than those of either the Moon or Mars. Craters may well exist, but are likely to be less sharp and clear-cut than those of Mars – since there is considerable evidence that the Martian craters are recent by geological standards, and active vulcanism is hardly to be expected upon a world such as Mercury. Whether there are any high Mercurian mountains we do not know, but in any case the tremendous extremes of temperature must have had marked effects upon the surface topography of the planet.

During 1972 there was considerable discussion in the popular Press about an alleged 'intra-Mercurian planet', moving round the sun at a distance less than that of Mercury. In fact this report was erroneous. During the last century a planet was believed to move in these torrid regions, and it was even given a name (Vulcan), but we are now confident that Vulcan does not exist. The only known natural body which can move inside the orbit of Mercury is the tiny asteroid Icarus.

THE TWINKLING OF SIRIUS

During February evenings the brilliant star Sirius is well placed for observation. Look for it in the south, rather low down. Though it is actually a white star of spectral class A, it seems to twinkle violently, flashing all the colours of the rainbow.

Twinkling, or scintillation, has nothing to do with the stars themselves. It is due entirely to the unsteady atmosphere of the Earth. When a star is low, its light is coming to the observer after having passed through a deep layer of atmosphere, so that the twinkling is increased. The effect is more noticeable with Sirius than with any other star, simply because Sirius is so brilliant.

It is sometimes said that stars twinkle, while planets do not. This is not entirely true; and when Mercury is seen this month, it will twinkle quite noticeably except when the air is exceptionally calm and steady. However, it is only right to add that a planet twinkles less than a star, because it appears as a small disk – whereas a star is effectively a point source of light.

March

New Moon: 5 March *Full Moon*: 18 March

Equinox: 20 March

Mercury is in inferior conjunction on 13 March and will not be visible during the month.

Venus also remains invisible since it is now nearing superior conjunction.

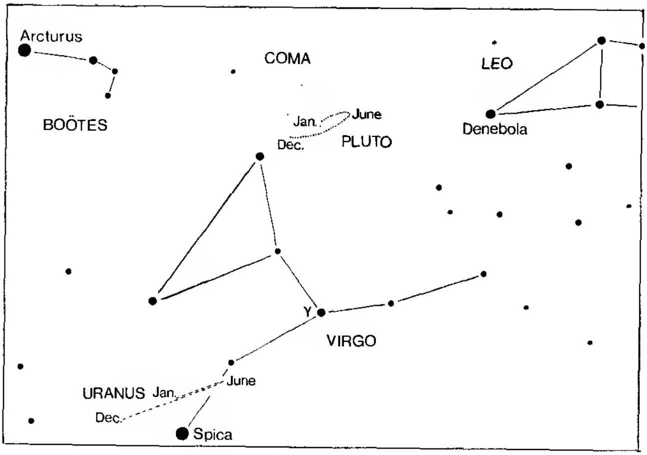
Mars is still a morning star in Sagittarius and continues to rise south of east about two hours before the Sun. Towards the end of March it passes into Capricornus, growing a little brighter (magnitude +1·3 to +1·1) and moving steadily towards the much brighter planet Jupiter.

Jupiter rises about two hours before the Sun at the end of March. It is beginning to grow brighter (magnitude –1·5 to –1·7) and is to be found in Capricornus with Mars in the same constellation, but farther west (see diagram in April notes).

Saturn is still to be seen in the evening sky, in the south at sunset and moving direct in Taurus (see diagram in October notes). The planet is now of magnitude +0·3, but is still brighter than the neighbouring stars of Taurus and Orion.

Uranus is nearing opposition and its retrograde movement carries it three degrees north of Spica on 7 March. This is the second of three conjunctions of the planet with this star, the first being on 20 December last, and the third in September next.

Pluto is at opposition on 23 March, and its position is shown on the diagram below, although it is too faint to be seen with small



Uranus and Pluto 1973

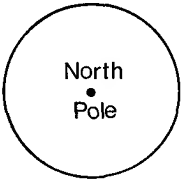
instruments (magnitude +14). The distance at opposition is about 2802 million miles (4509 million km).

URANUS

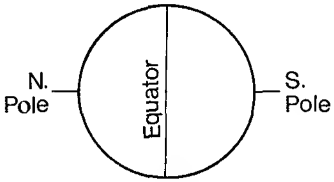
This is a good time to look at the seventh planet, Uranus. It is near Spica, and is just visible with the naked eye to anyone who knows exactly where it lies. Binoculars will show at once that it is not a star; and with a modest telescope its pale greenish disk is very evident.

Uranus is a giant world. Its diameter is 29,300 miles, and its volume is roughly 50 times that of the Earth. Oddly enough, its surface gravity is only fractionally greater than the Earth's. This is because Uranus is so much less dense; its outer layers, at least, are gaseous. Of course, the escape velocity is high: almost 14 miles per second.

Not much can be seen on Uranus disk, which ranges between 3 and 4 seconds of arc in diameter. To complicate matters, we see the planet under most peculiar conditions. The axial tilt is 98 degrees, which is more than a right angle; therefore there are times when we see one of the poles in the centre of the disk! This will happen in 1985. The north pole of Uranus will face us, and the south pole will be turned away from the Earth, so that we cannot see it at all. By the year 2007 conditions will be different again; the poles will lie at the planet's limbs, and we will have a 'bird's-eye view' of the equator. The reason for this remarkable inclination of the axis is unknown. It is not shared by Neptune, which is in many ways similar to Uranus.



1985



2007

Uranus was not known in ancient times; it was discovered in 1781 by William Herschel, then an unknown amateur but later to become the most famous observer of his day. Five satellites have been detected. Titania and Oberon are the easiest to observe, but neither is as large as our Moon, so that a telescope of fair size is needed.

Now that a rocket probe has been sent out toward Jupiter, it is no longer fantastic to suggest that before long a vehicle may bypass Uranus. Indeed, this was on the programme of the much-publicized 'Grand Tour', in which the plan was to send a probe from Jupiter out to Uranus and subsequently to Neptune (an alternative Tour took in Jupiter, Saturn and Pluto). Because the planets are not often suitably placed for experiments of this sort, the Tour had to begin around 1977, and Uranus would have been reached in 1985. Unfortunately the American authorities have now cancelled the programme, on financial grounds; but there is every reason to suppose that the Russians will attempt it. If they are successful, we may collect some more reliable information about this unusual, bitterly cold giant world.

Uranus does not move quickly in the sky. It will remain in Virgo until 1977, and will then lie in Libra until 1982, when it will pass into Scorpius.

GAMMA VIRGINIS

Also shown on the chart on page 65 is the star Gamma Virginis, sometimes known by its old proper names of Arich, Postvarta or Porrima. It is easy to locate, since it lies at the base of the 'bowl' of Virgo. It is above the third magnitude, so that it is bright enough to be reasonably conspicuous even though it is not striking.

Look at Arich with a telescope, and you will see that it is double. The components are virtually equal in brightness, so that it is impossible to tell which is to be regarded as the senior member; they make up a pair of identical twins. Also, they are equal in spectral type, and therefore in surface temperature. Each is classed as F0, so that their surfaces are rather hotter than that of the Sun. The distance from us is 32 light-years.

Arich is a splendid example of a binary star. The revolution period is just under 180 years, and the orbits are highly eccentric, so that the apparent separation changes markedly. In 1780, William Herschel measured it as 5″.7. By 1835 it had closed up; according to W. Struve, using the 9½ in. Fraunhofer at Dorpat (then the largest and best in the world) the separation was only 0″.5, so that the pair appeared simply as an elongated star. In February 1836 Sir John Herschel, using his 20-ft. focal length reflector at the Cape of Good Hope, recorded that 'γ Virginis, at this time, is to all appearance a single star. I have tormented it under favourable circumstances, with the highest powers I can apply to my telescopes, consistently with seeing a well-defined disk, till my patience has been exhausted. . . . I have not been able to procure any decisive symptom of its consisting of two individuals.'

The famous English amateur astronomer Admiral W. H. Smyth calculated an orbit, according to which the revolution period was fixed at approximately 180 years. We now know that Smyth was quite correct. Gradually, Arich 'opened out' again. The separation was 1″.2 in 1840 (W. R. Dawes), 4″.6 in 1870 (E. Dembowski) and over 5″ in 1880 (J. Jedrzejewicz). Forty years later the separation exceeded 6″, making Arich one of the finest doubles in the entire sky. Since then the pair has been closing up again. It is still a magnificent object in even a small telescope, but it will not remain so, and by about the year 2015 it will again appear single except when observed with very large instruments.

Binary stars have a wide range in period. Among brighter examples, Zeta Herculis has an orbital revolution of only 34 years; the components are rather unequal (magnitudes 3 and 6½), but are easily separated when at their widest, as they will next be around 1988; the separation will then be 1″.6. Gamma Leonis, well on view during March evenings, is another splendid system. The components are of magnitudes 2¼ and 3¾; the period is 407 years, so that the apparent changes in position are very slow. The primary is an orange star of type K. The distance from us is 190 light-years, so that even the fainter component is more luminous than either of the twins making up Arich.

HUGO VON ZEIPEL

This year is the centenary of the birth of H. von Zeipel, a famous Swedish astronomer who became Director of the Uppsala Observatory. His main work was in connection with star-clusters, in which he was accepted as one of the world's leading authorities.

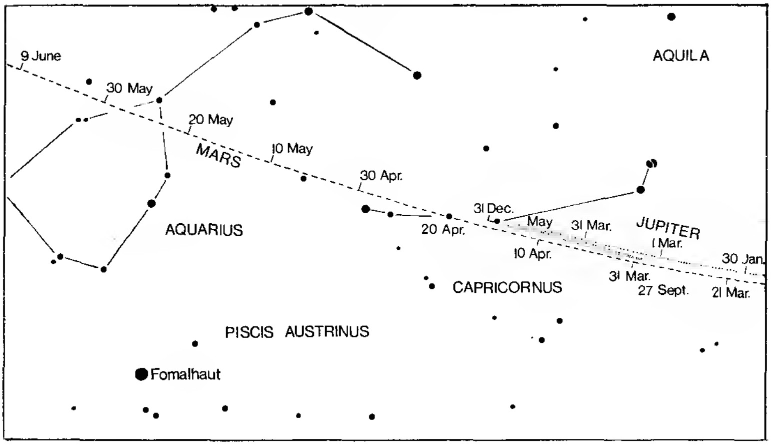
April

New Moon: 3 April *Full Moon*: 17 April

Mercury is at greatest western elongation (28°) on 10 April and is then a morning star, but it will be very low in the south-east and difficult to see in the dawn sky.

Venus is in superior conjunction on 9 April. After this it becomes an evening star, and by the end of the month it sets in the west nearly an hour after the Sun.

Mars continues to rise about two hours before the Sun, and is moving direct in Capricornus. The planet grows steadily brighter as it comes nearer to the Earth (magnitude +1·1 to +0·7). Mars passes less than a degree south of Jupiter on 6 April, but this conjunction occurs in the afternoon. Owing to the rapid motion of Mars it will be possible to see this planet to the west of Jupiter on the morning of 6 April, and to the east of that planet on the following morning (see diagram below).



Mars (March-June) and Jupiter

Jupiter is a brilliant morning star (magnitude –1·7 to –1·9) rising in the south-east about two hours before sunrise. The conjunction of Mars with Jupiter on 6 April is referred to above, and is shown in the diagram.

Saturn sets at midnight in the west, above Aldebaran and to the right of the sloping figure of Orion. The magnitude of Saturn remains at +0·3, which is much the same as that of Rigel, at the foot of Orion.

Uranus is at opposition on 11 April and will be found a few degrees from Spica (see diagram in March notes). At opposition the distance of Uranus from the Earth is about 1617 million miles (2602 million km), and it will then just be visible to the naked eye (magnitude +5·7). A small telescope will show the planet as a greenish disk.

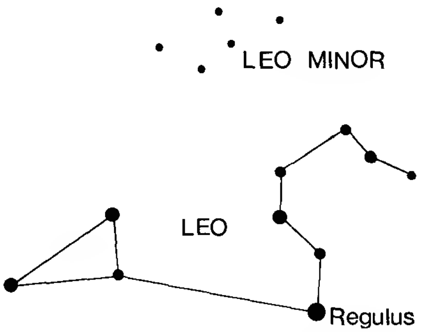
VENUS BEYOND THE SUN

Venus, like Mercury, is difficult to study under favourable conditions, mainly because it is full only when on the far side of the Sun – as it will be this month. Naturally, it is also then at its greatest distance from the Earth. It can be located by means of a telescope fitted with really accurate setting circles, but on the whole the procedure is not to be recommended. First, there is little real point in it; when very close to superior conjunction no details can be seen on Venus, and even the phase cannot be made out. Secondly, there is always a certain amount of danger in trying to observe a body which is within a degree or two of the Sun.

In one book, published quite recently, it was said that Venus could be found in daylight by sweeping with binoculars. This is true enough when Venus is well away from superior conjunction; but it is a most unwise experiment. If the Sun enters the field of view, as is always possible, the observer's eye is certain to be badly damaged. Even when using a telescope with setting circles, never sweep aimlessly around if Venus is not found as expected. Any sweeping should be carried out with the greatest care — and always sweep away from the Sun.

MINOR CONSTELLATIONS

The evening sky in March is dominated by large, important constellations. Ursa Major is very high up, Orion is still very much in evidence during the earlier part of the night; in the south we have Leo, with its celebrated Sickle and its first-magnitude star Regulus. But there are other groups, much less important, and in some cases hardly deserving of separate identities. What, for instance, is the justification for Leo Minor, the Little Lion, with no star brighter than the fourth magnitude? It is not an ancient group; it was formed by the Danzig astronomer Hevelius as recently as 1690.



Ptolemy, in his *Almagest* of the second century A.D., listed 48 constellations – 21 northern, 12 Zodiacal and 15 southern. All his groups are still to be found on our modern maps, though the boundaries have been drastically modified, and the old Argo Navis (the Ship) has been unceremoniously cut up into four parts, on the pretext that it was over-sized and unwieldy. Then, in the 17th and 18th centuries, various astronomers took it upon themselves to add to the list of constellations. In some areas this was justifiable; Ptolemy could know nothing about the stars of the far south, which never rose above the horizon of his home in Alexandria. Other additions (such as Leo Minor!) were less easy to understand. Also, there are some proposed groups which have been rejected by modern authorities, presumably because they were obviously unsuitable – and perhaps, also, because they had barbarous names; J. E. Bode proposed groups such as Sceptrum Brandenburgicum, Globus Aerostaticus, Telescopium Herschelii, and Officina Typographica!

It may be of interest to give a list, showing the way in which the current names have been introduced over the centuries. The names in use today have been approved by the International Astronomical Union, the controlling body of world astronomy.

Ptolemy's Originals

Andromeda
Aquarius
Aquila
Ara
Argo Navis
Aries
Auriga
Boötes
Cancer
Canis Major
Canis Minor
Capricornus
Cassiopeia
Centaurus
Cepheus
Cetus
Corona Australis
Corona Borealis
Corvus
Crater
Cygnus
Delphinus
Draco
Equuleus
Eridanus
Gemini
Hercules
Hydra
Leo
Lepus
Libra
Lupus
Lyra
Ophiuchus
Orion
Pegasus
Perseus
Pisces
Piscis Austrinus
Sagitta
Sagittarius
Scorpio
Serpens
Taurus
Triangulum
Ursa Major
Ursa Minor
Virgo

Added by Tycho Brahe, late 16th century:

Coma Berenices

Added by J. Bayer, 1603:

Apus
Chamæleon
Dorado
Grus
Hydrus
Indus
Pavo
Phœnix
Triangulum Australe
Tucana
Volans

(All in the southern hemisphere; not visible from Britain)

Added by Royer, 1679:

Columba
Crux Australis

Added by Hevelius, 1690:

Camelopardalis
Canes Venatici
Lacerta
Leo Minor
Lynx
Monoceros
Scutum
Sextans
Vulpecula

Added by Lacaille, 1752:

Antlia
Cælum
Circinus
Fornax
Horologium
Mensa
Microscopium
Musca
Norma
Octans
Pictor
Pyxis
Reticulum
Sculptor
Telescopium

(All in the southern hemisphere; most of them invisible from Britain)

Strange that Crux, so beloved of all dwellers in the southern hemisphere, should date back less than three centuries as a separate constellation! Previously it had been included with Centaurus.

Some of these names have been modified since originally proposed. For instance, Piscis Volans (the Flying Fish), Columba Noachi (Noah's Dove), Vulpecula et Anser (the Fox and Goose) and Reticulus Rhomboidalis (the Rhomboidal Net) have become respectively Volans, Columba, Vulpecula and Reticulum. Undoubtedly these changes are for the better.

From time to time there have been suggestions for making further revisions to the constellation list, or even of revising it altogether (one writer even wanted to substitute politicians for the present mythological characters; one can well imagine what the result would have been!). However, the present system, irrational though it may be, has become so firmly established that it will certainly never be altered in our time.

May

New Moon: 2 May *Full Moon*: 17 May

Mercury is in superior conjunction on 20 May and is too close to the Sun to be seen during the month.

Venus is now an evening star and by the end of May it sets more than an hour after the Sun. Venus passes less than two degrees north of Saturn on May 30, but although Venus is very bright, it may be more difficult to find Saturn in the twilight sky (magnitudes: Venus –3·4, Saturn +0·3).

Mars is still a morning star rising about two hours before the Sun, but it now passes into Aquarius. It should be quite easy to recognize as it is now becoming a very bright object (magnitude +0·7 to +0·3).

Jupiter is now a notable object in the morning sky (magnitude −1·9 to −2·1) and by the end of May it rises at midnight. On 31 May it reaches a stationary point, about a degree west of the fourth magnitude star Theta Capricorni (see diagram in April notes).

Saturn is approaching conjunction, and by the end of the month it sets less than an hour after the Sun.

Neptune is at opposition on 27 May at a distance of about 2720 million miles from the Earth (4380 million km). Its position at this time is shown in the diagram on page 55, but the planet is not visible to the naked eye. In a small telescope it appears as a small disk of magnitude +7·7.

THE FIRST AMERICAN IN SPACE

This month marks the twelfth anniversary of America's entry into space. On 5 May 1961 Commander Alan Shepard blasted off from Cape Canaveral, and reached a peak altitude of 116 miles. He did not go round the Earth; his mission was an up-and-down 'sub-orbital hop', and it lasted for only 15½ minutes, but it was immensely significant. At that time only one other man, Yuri Gagarin, had travelled above the atmosphere.

The situation a dozen years ago was very different from that of today. Manned space-flight was something entirely new, and there were many unknown factors to be taken into account. Yuri Gagarin's flight, on 12 April 1961, had laid some of the bogys; he was neither battered by meteorites, affected by space-sickness, or seared by radiations. When he came down, after 1 hour 48 minutes, he was in excellent physical shape. However, it was generally thought that at this period Russian technology was considerably more advanced than anything the United States could attempt, and the American rocket programmes had been dogged by mishaps and failures.

There had been seven trainee astronauts of the U.S. Project Mercury, and there had been a great deal of speculation as to who would have the honour of making the first attempt. The choice fell on Shepard, and he duly took off; he did so in a blaze of publicity – a strange contrast to Gagarin's flight, which had not been announced to the world until it was over. Shepard was in touch with ground control, of course, and everything was broadcast over the ordinary radio stations, so that everyone knew exactly what was going on. There were no hitches. Shepard had his first experience of zero gravity; eventually he landed in the sea some 300 miles away from Cape Canaveral (since re-named Cape Kennedy), and hundreds of reporters and technicians on board the aircraft-carrier *Lake Champlain* saw him step from a helicopter on to the deck after he had been successfully picked up from his capsule.

Shepard had shown the way. In July Virgil Grissom followed with a second sub-orbital journey, also lasting for a quarter of an hour; it was in the following February (1962) that Colonel John Glenn became the first American to orbit the Earth.

It seems a very long time ago, and the careers of those pioneer astronauts have followed very different courses. Gagarin was tragically killed in an air accident; Grissom was one of the three victims of the disastrous fire at Cape Kennedy in 1967; Glenn retired from space research without making another flight. For a time Shepard too was off the 'active list', because of ear trouble. Against all the odds he conquered the disability, returned to practical astronautics, and in 1971 he became commander of Apollo 14, which landed in the Fra Mauro region of the Moon. Together with Edgar Mitchell, he explored the lunar surface, making two protracted 'moonwalks' and almost reaching the rim of the structure known unofficially as Cone Crater. It was a personal triumph for Shepard, whose selection as commander had been strongly criticized; it was also a measure of the rate at which American technology had progressed. Remember, only ten years separated Shepard's tentative 'hop into space' from his journey to the surface of the Moon.

THE DISCOVERERS OF NEPTUNE

Neptune, at opposition this month, is much too faint to be seen with the naked eye. Its magnitude is $7\frac{3}{4}$, which means that optical aid is essential if it is to be observed; and there are no 'pre-discovery' records of it – in contrast to Uranus, which was seen by several eminent astronomers without being recognized as anything but a star.

The story of the discovery of Neptune is well known. Irregularities in the movements of Uranus led to the suspicion that an unknown planet must exist; the position of this planet was calculated independently by Adams in England and Le Verrier in France; and the first optical identification was made at Berlin by Galle and d'Arrest on the basis of Le Verrier's work. But much preliminary work had been done. Originally it had been believed that the laws of gravitation might be slightly modified at great distances from the Sun, so that Uranus would not behave in the expected manner; this was the view of George Biddell Airy, who became Astronomer Royal in 1835.

Apparently Alexis Bouvard, one of the mathematicians working upon the problem of Uranus, was the first man to be converted to the theory of an extra-Uranian planet, but the first clear statement is due to the credit of an English amateur, the Rev. Thomas Hussey, Rector of Hayes in Kent. On 17 November 1834 Hussey wrote to Airy, saying that he had corresponded with Bouvard, and suggesting that a search be made for the planet which was pulling Uranus out of position. In Hussey's letter, he said that Bouvard 'fully acquiesced' in the idea, adding that calculation to find the position of the planet 'would be more laborious than difficult; that if he had the leisure he would undertake them and transmit the results to me, as the basis of a very close and accurate sweep'. Unfortunately Airy was singularly unenthusiastic, and Hussey's proposed 'sweep' was never made.

In 1835 Jean Valz studied the movements of Halley's Comet, which came to perihelion in that year, and referred to the possibility of 'an invisible planet, located beyond Uranus' which was pulling on the comet. Valz suggested that after five or six cometary returns, it might be possible to track down the disturbing body – though since Halley's Comet has a period of 76 years, the investigation would be inordinately long. Valz was supported by Friedrich Nicolai, Director of the Mannheim Observatory, who found that Halley's Comet came to perihelion a day later than expected: 'One immediately suspects that a trans-Uranian planet . . . might be responsible for this phenomenon'.

At Palermo, in Sicily, Niccolo Cacciatore observed an object which he thought might be a remote planet (actually, it was not Neptune; neither was the object reported by a Swiss amateur, Louis Wartmann, from his private observatory in Geneva). Gradually, the idea of a trans-Uranian planet took root. It was supported by many mathematicians, including Friedrich Bessel, who achieved lasting fame in 1838 when he became the first man to announce the measurement of the distance of a star. Johann von Mädler, the great observer of the Moon, wrote in

1841 that 'We arrive at a planet acting upon and disturbing (Uranus); we may even express the hope that analysis will at some future time realize in this her highest triumph, a discovery made with the mind's eye, in regions where sight itself is unable to penetrate.'

In 1842 Bessel visited England, and told Sir John Herschel that he planned to make the necessary calculations, using observations of Uranus made by his pupil Friedrich Flemming. By ill fortune Flemming died suddenly, and Bessel became seriously ill; in 1846 he too died. Thus the solution to the problem was left to Adams and to Le Verrier. On 23 September 1846 Johann Galle and Heinrich d'Arrest, using the 9 in. refractor at Berlin located a star of the eighth magnitude which caused d'Arrest to exclaim: 'That star is not on the map!' Neptune had at last been tracked down.

June

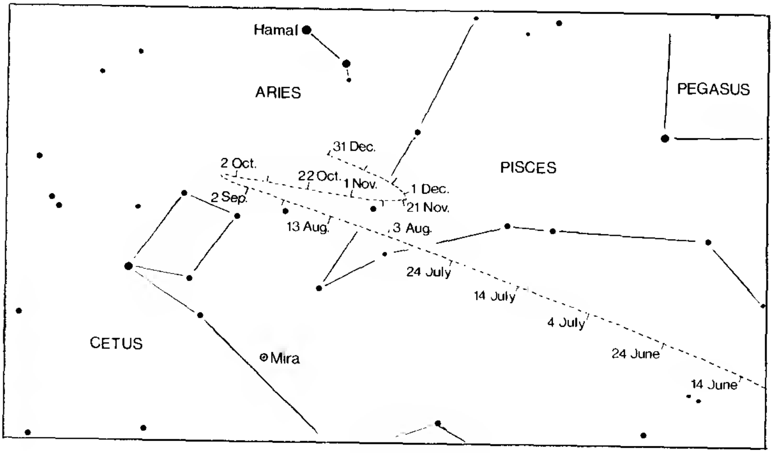
New Moon: 1 June and 30 June *Full Moon*: 15 June

Solstice: 21 June

Mercury is at greatest eastern elongation (25°) on 22 June and for a few days before this date it may be possible to glimpse the planet low down in the north-west after sunset. The planet is not very bright and will not be easy to find. By contrast, the brilliant planet Venus is in the same neighbourhood, but much higher in the sky.

Venus is an evening star, setting more than an hour after the Sun to the north of west (magnitude −3·4).

Mars is still a morning star, but by the end of June it will rise at midnight. At the beginning of the month it passes into Pisces. The planet is now a brilliant object (magnitude +0·3 to −0·1)



Mars, June to December 1973

and is quite conspicuous in a part of the sky which contains no very bright stars.

Jupiter now rises before midnight in the south-east in Capricornus, and will be in the south at sunrise. The planet is approaching opposition, and growing even brighter (magnitude −2·1 to −2·3).

Saturn is in conjunction on 15 June and will not be visible during the month.

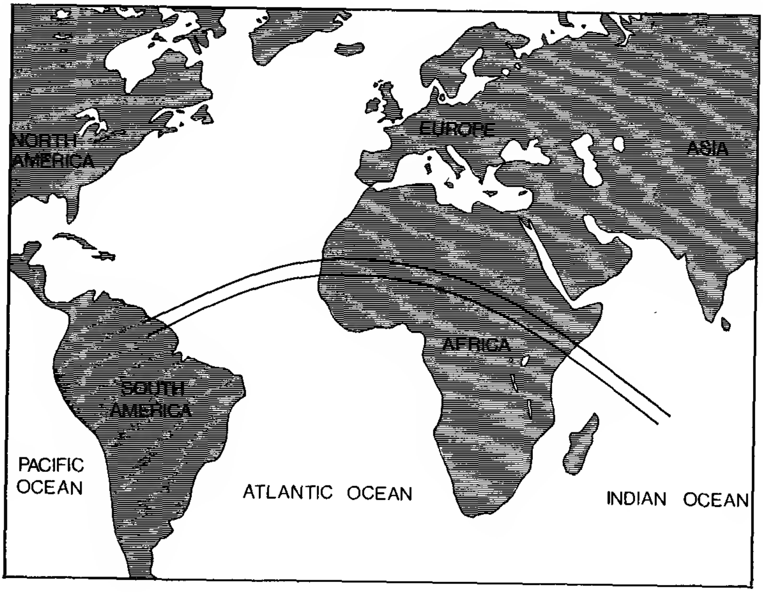
A total eclipse of the Sun on 30 June has the unusually long duration of 7 min. 04 sec. The path of totality begins in Guyana, crosses the north Atlantic Ocean and North Africa, to end in the Indian Ocean. A partial eclipse will be seen from most of Africa, and south and west Europe. In the extreme south-west of England a small partial eclipse will be visible just before midday (see notes below and one page 114).

The Long Eclipse

This month sees one of the longest possible total eclipses of the Sun. In parts of North Africa it will last for more than seven minutes. Unfortunately little of the eclipse will be seen from Britain; a small partial is visible from Cornwall, and will be at its greatest phase at 11.10 G.M.T. as seen from Penzance – but only 4 per cent. of the Sun will be covered. (Let us again repeat the old warning: never look direct at the Sun with any telescope or binoculars, even if a dark filter is used – and it is also most unwise to stare at the Sun for more than a second or so. The human eye is a delicate thing.)

The track of totality touches the Earth at sunrise on the border of Brazil and Guyana, and leaves the South American continent along the Guyana coast. The shadow then crosses the Atlantic, passing over Santo Antão and São Vicente (Cape Verde Islands) at 10^{h} 22^{m}. (All times are given in G.M.T.) The track reaches Africa on the coast between Cap Blanc and Tanit, in

Mauritania, at 10.39; totality here lasts for over 6 minutes. The path reaches the Mali border at 11.05; it is north of Timbuktu at 11.12, and north of Gao at 11.24 (totality 7 minutes 2 seconds). The track then turns south-east, crossing the Mali border again at 11.34 (totality 7 minutes 3.9 seconds). The width of the track of totality at this point is 161 miles – within ten miles of the maximum possible. The track then moves across the border between Niger and Chad, just north of Lake Chad (12.05 G.M.T.) and then moves over north-east Uganda and over Kenya. The shadow leaves Africa at the coast of the Somali Republic, between the equator and Chiamboni, at 13.08 G.M.T.; the duration here is 4 minutes 28 seconds. The path leaves the Earth at sunset in the Indian Ocean, between Madagascar and the Indian mainland. The general track of the eclipse is shown in the diagram.



Total Solar Eclipse

Most of the European and North American expeditions are likely to station themselves in Mauritania. Inland sites in this country are favourable, partly because of the favourable climate – the chances of a cloudy day are extremely slight at this time of year – and partly because Mauritania has a government which, by African standards, is stable; Mali, on the other hand, is Chinese Communist, and travel to and from it is naturally much more difficult. The chief disadvantage about inland Mauritania is that there are not many roads, and accommodation is very restricted. However, it is likely that many astronomers will congregate there.

The importance of a total eclipse is that while the brilliant disk of the Sun is hidden, the solar atmosphere can be observed without the need for using complicated equipment. Totality is the only time when the corona can be seen with the naked eye – and from Earth, the only time when the outer part of it can be studied at all. The spectacle is unrivalled in Nature; the corona, the chromosphere, and the prominences surrounding the dark body of the Moon present a sight which cannot be described adequately in cold print. Without eclipses, our knowledge of the Sun would be much less than it actually is. Originally there was some doubt as to whether the prominences belonged to the Sun or to the Moon; in fact, the question was still regarded as open until well into the nineteenth century.

Yet from a purely scientific point of view, the importance of total eclipses may be nearing an end. Once it becomes possible to carry out long-continued observations of the Sun from orbital stations, or from the surface of the Moon, there will be no atmospheric limitations; and it is quite possible that if the space-research programme progresses at its present rate, the 1973 eclipse will be the last to be studied by full-scale international teams. Be this as it may, nothing can ever detract from the sheer beauty of the spectacle.

This month's eclipse is important not only because of its length (7 minutes is very exceptional!) but because it will be the last to be visible from a convenient location for some time. The remaining eclipses of the present decade are:

1973 Dec. 24. Annular (mid-Atlantic).
1974 June 20. Brief totality over South Indian Ocean.
1976 April 29. Annular for 7 minutes in Mediterranean area.
1976 October 23. 5-minute totality in South Indian Ocean.
1977 April 18. 7-minute totality in South-West Africa.
1977 October 12. Total for 3 minutes over parts of the Pacific.
1979 February 26. 3-minute totality in Hudson's Bay area.
1979 August 22. Annular for 6 minutes – but only in Antarctica.
1980 February 16. Total for 4 minutes in East Africa.
1980 August 10. Total for 3 minutes in West Pacific area.

In addition there are partial eclipses on 1974 December 13, 1975 May 11 and November 3, and 1978 April and October.

The next total eclipse visible from England will be that of 1999 August 11, when Cornwall will be the favoured area.

VEGA AND CAPELLA

Throughout evenings in summer, the night sky is characterized by the so-called 'Summer Triangle', consisting of three first-magnitude stars: Vega in Lyra, Altair in Aquila, and Deneb in Cygnus. Of the three Vega appears much the brightest, and is decidedly blue in colour. It is of magnitude 0, and is more brilliant than any other star visible from England apart from Sirius and Arcturus. During late evenings in June it is practically overhead.

On the opposite side of the Pole lies Capella, whose brightness is almost exactly equal to that of Vega but is of different type; its colour is yellow. It occupies the overhead position during winter evenings. Obviously, when Vega is high up Capella is low down, and vice versa. Neither actually sets from the latitude of London, but both become very low, and during evenings in June Capella almost grazes the horizon.

Arcturus is well on view this month. Here we have a star of yet another colour – a beautiful light orange, contrasting sharply with the steely blue of Vega.

July

Full Moon: 15 July *New Moon*: 29 July

Earth is at aphelion (farthest from the Sun) on 4 July, when its distance will be 94,500,000 miles (152,100,000 km).

Mercury is in inferior conjunction on 20 July, and will not be seen during the month.

Venus continues to set rather more than an hour after the Sun and remains at about the same brightness (magnitude −3·4).

Mars rises in the east at midnight at the beginning of July, and is now a brilliant object (magnitude −0·1 to −0·6) in Pisces, coming north of the equator in the first week of the month. Mars is at perihelion on 26 July, when it is 128 million miles (207 million km) from the Earth – about 27 million miles nearer to the Sun than when it is at aphelion.

Jupiter is at opposition on 30 July and is then at its brightest (magnitude −2·4) and nearest to the Earth — on this occasion about 379 million miles (610 million km). These figures show that the planet is nearer to the Earth and much brighter than it has been for several years, but it is well south of the equator and will seldom be seen as much as 20° above the southern horizon at midnight.

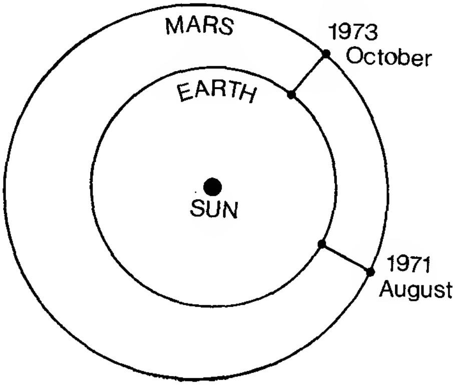
Saturn is a morning star in Taurus, rising an hour or more before sunrise. The planet is moving direct, its magnitude is still about +0·3, and it will be seen some degrees north of the figure of Orion.

MARS IN THE NORTHERN HEMISPHERE

In the summer of 1971 Mars was at its closest to the Earth, but it was also well south of the celestial equator, and European and North American observers were inevitably handicapped by poor seeing and atmospheric unsteadiness. By the time Mars moved north, toward the end of the year, it had receded so much that even large telescopes would show little on its surface. In 1973 conditions will be better. Mars will not be quite so close, but it will be much higher up, and in early July it moves across the celestial equator; it will remain in the northern hemisphere until the end of the year.

Mars will be found in Pisces, which is one of the least prominent of the Zodiacal groups (only Libra and Cancer are equally obscure). During August the planet will cross a corner of Cetus, the Whale or Sea-monster; here again we have a constellation which is not in the official Zodiac, but it should be added that unlike Ophiuchus it does not actually cross the ecliptic. Mars will then move into Aries, and will subsequently retrograde back into Pisces before returning to Aries at the end of the year.

During July the Earth is at aphelion and Mars is at perihelion. The Earth's orbit is so nearly circular that the effects on our climate are relatively slight; but the path of Mars is much more eccentric. The closest oppositions take place when Mars comes to opposition and to perihelion at about the same time – as happened in 1971; this year, however, opposition is

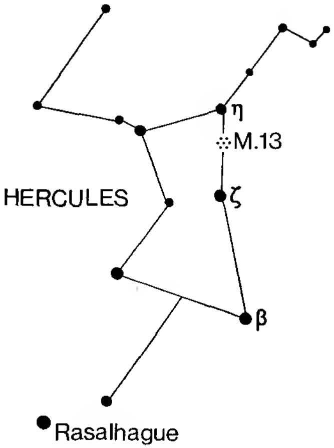


not due until three months after perihelion. In the diagram above; the opposition positions for 1971 and 1973 are shown.

The Globular Cluster in Hercules

Globular clusters are highly interesting and important objects. Unfortunately all of them are very remote, and only three can be distinctly seen with the naked eye. Of these, the two brightest – Omega Centauri and 47 Tucanæ – lie so far south that they never rise from the latitude of Greenwich. The third is Messier 13, in Hercules.

Look for it with the naked eye on a dark evening in July, and you should be able to see it. It is to be found between the stars Zeta and Eta Herculis, rather closer to Eta. It was discovered by Edmond Halley in 1714, so that it had escaped the eagle eyes of men such as Tycho Brahe (who also, rather surprisingly, overlooked the Andromeda Nebula). It may contain up to half a million stars, and is characteristically symmetrical; a modest telescope will resolve much of it, and it is a truly glorious object when seen with an adequate instrument. The distance is 6·9 kiloparsecs, or 22,500 light-years. (One kiloparsec is equal to 1000 parsecs, or 3260 light-years.)



Since globular clusters lie near the edge of the main galactic system, and belong to Population II, we have a lop-sided view of the general distribution; and it was by studying this distribution that Harlow Shapley was able to draw up the first reliable picture of the size of the Galaxy. Most of the globulars are in the southern hemisphere, with a marked concentration toward the constellation of Sagittarius. Messier, in his celebrated catalogue of 1781, listed a number of them, and it may be interesting to list the globulars which he recorded:

Messier number	*NGC*	*R.A.*	*Dec.*	*Constellation*	*Mag.*	*Dist, kps.*	*Apparent diameter, min. of arc*
2	7089	21 30·9	−01 03	Aquarius	6·3	16	12
3	5272	13 39·0	+28 38	Canes Venatici	6·4	14	19
4	6121	16 20·6	−26 24	Scorpius	6·4	2·3	23
5	5904	15 16·0	+02 16	Serpens	6·2	8·3	20
9	5333	17 16·2	−18 28	Ophiuchus	7·3	7·9	6
10	6524	16 54·5	−04 02	Ophiuchus	6·7	5·0	12
12	6218	16 44·6	−01 52	Ophiuchus	6·6	5·8	12
13	6205	16 39·9	+36 33	Hercules	5·7	6·9	23
14	6402	17 35·0	−03 15	Ophiuchus	7·7	7·2	7
15	7078	21 27·6	+11 57	Pegasus	6·0	15	12
19	6723	16 59·5	−26 11	Ophiuchus	6·6	6·9	5
22	6656	18 33·3	−23 58	Sagittarius	5·9	3·0	17
28	6626	18 21·5	−24 54	Sagittarius	7·3	4·6	15
30	7099	21 37·5	−23 25	Capricornus	8·4	13	9
53	5024	13 10·5	+18 26	Coma	7·6	20	14
54	6715	18 52·0	−30 32	Sagittarius	7·3	15	6
55	6809	19 36·9	−31 03	Sagittarius	7·6	5·8	15
56	6779	19 14·6	+30 05	Lyra	8·2	14	5
62	6266	16 58·1	−30 03	Ophiuchus	8·9	6·9	6
68	4590	12 36·8	−26 29	Hydra	9	12·0	9
69	6637	18 28·1	−32 23	Sagittarius	8·9	7·2	4
70	6681	18 40·0	−32 21	Sagittarius	9·6	20	4
71	6838	19 51·5	+18 39	Sagitta	9	5·5	6
72	6981	20 50·7	−12 44	Aquarius	9·8	18	5
75	6864	20 03·2	−22 04	Sagittarius	8·0	24	5
79	1904	05 22·2	−24 34	Lepus	7·9	13	8
80	6093	16 14·1	−22 52	Scorpius	7·7	11	5
92	6341	17 15·6	+43 12	Hercules	6·1	11	12
107	6171	16 29·7	−12 57	Ophiuchus	9·0	17	8

As the Messier list contains 29 globulars out of 108 objects, it might be thought that globular clusters are quite common. In fact, they are not; the total number known in our Galaxy is only a little over one hundred.

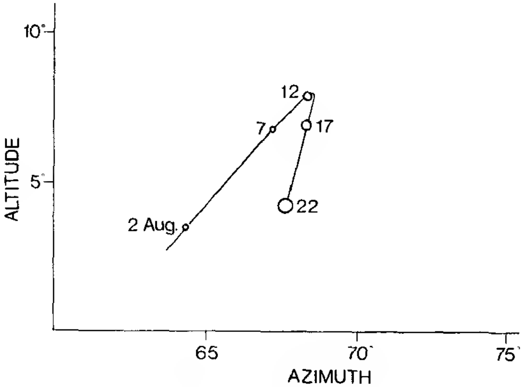
JUPITER AT ITS BRIGHTEST

Jupiter is so far from the Sun, and from the Earth, that its variations in opposition brilliancy are not very noticeable. This year it is at its maximum, and normally it is outshone only by the Sun, the Moon and Venus – though on rare occasions (such as later in 1973) it can also be surpassed by Mars. Unfortunately for European and North American observers Jupiter is still well south of the equator, and so is low down; but it is now moving northward. At the opposition of 1974 it will be in Capricornus; in 1975, in Aquarius; and in 1976 in Pisces, after which it will remain in the northern hemisphere for another six years.

August

Full Moon: 14 August *New Moon*: 28 August

Mercury is at greatest western elongation (19°) on 8 August, and may be seen at this time as a morning star to the north of east just before sunrise. The diagram shows the changes in altitude and azimuth of Mercury on successive mornings when the Sun is six degrees below the horizon – this is about thirty-five minutes before sunrise in early August. The changes in brightness are roughly indicated by the size of the circles, and these show that Mercury is much brighter after the date of western elongation.



Mercury, August 1973

Venus remains an evening star of magnitude – 3·4, setting about an hour after the Sun. This state of affairs, with an almost unchanging appearance of the planet lasting for six months or more (see page 55) is most noticeable when Venus comes to greatest eastern elongation at the end of the year.

Mars now rises in mid-evening, and is a brilliant object in the eastern sky (magnitude –0·6 to –1·2). The planet is actually several degrees south of the ecliptic, and its rapid motion takes it across one corner of the constellation Cetus at the end of the month. It will then be in Aries, and will be seen below the second-magnitude star Hamal.

Jupiter is still a dominating object in the night sky, although it is now beginning to fade a little (magnitude –2·4 to –2·3). It is still moving retrograde in Capricornus and will be visible until shortly before dawn. Jupiter can now be seen in a dark sky in the late evening hours, and this affords a good opportunity to follow the rapidly changing phenomena of the four great satellites with a small telescope.

Saturn moves into Gemini at the beginning of August, and rises at midnight in a dark sky. The rings are now open at their widest, and can easily be seen with a small instrument. Saturn passes about a degree south of the crescent Moon (at Last Quarter) on the night of 23 August.

The Changing Aspects of Saturn's Ring System

This year Saturn's ring system is seen to its best advantage. The rings are at their widest; and to improve matters still further from the point of view of European and North American observers, the planet is in Gemini – as far north in the sky as it can ever move. The south face of the ring system is displayed; that is to say, the planet's north pole is covered. Even a small telescope will show the celebrated Cassini Division.

In the coming years the rings will close up again, until in 1979-80 they will be edgewise-on to the Earth. This last happened in 1966. Undoubtedly the rings are very thin, but it is not correct to say (as some books do) that they disappear completely when edge-on. An adequate telescope will still show them, though admittedly as nothing more than an excessively thin, faint line of light. After 1980 the north face of the system will be displayed; the rings will again be wide open in 1988, but in that year Saturn will be in Sagittarius, badly placed for European observers. The succeeding edgewise-presentation will take place in 1995-6, with Saturn lying in Pisces.

The present summer is obviously a good time to look for minor divisions in the rings. Encke's Division has been recorded on many occasions, but does not seem to be a true gap of the same kind as Cassini's; and the other Divisions which have been reported from time to time seem to be very dubious.

OLD IDEAS ABOUT SATURN'S RINGS

With the rings so well on view, this may be a suitable moment to say something about very early observations of them. Galileo first observed the rings, in 1610, but did not realize their nature; he believed Saturn to be a triple planet, and was very surprised when, in 1612, he found that he could no longer see the companions. This was in fact hardly surprising, as the rings were edge-on during that year. Later, Galileo re-observed them, but he never solved the mystery.

Observers during the first part of the 17th century were no more successful. Hevelius of Danzig believed Saturn to be elliptical in shape, with two appendages attached to the surface. The French mathematician de Roberval suggested that Saturn must be surrounded by a hot zone giving off vapours, reflecting sunlight off the edges but appearing opaque when seen in depth. Sir Christopher Wren – at this stage a professional astronomer; his fame as an architect was yet to come – thought that Saturn had an elliptical corona, meeting the globe in two places and rotating with Saturn once in each sidereal period. However, before Wren published his theory, Christiaan Huygens correctly stated that the cause of the strange appearance was 'a flat ring'. Characteristically, Wren accepted this at once. Others did not. Honoré Fabri, a French Jesuit, claimed that the aspect of Saturn could be explained by the movements of four satellites – two dark and two bright. A pamphlet published by Divini, though probably written by Fabri, was little more than a vitriolic attack on Huygens. The Fabri theory was easily refuted; and within a few years all astronomers accepted the ring hypothesis. Even Fabri was forced to do so in 1665.

THE PERSEIDS

Early August is the best time of the year for seeing meteors. Conditions in 1973 are favourable; the Moon is full on the 14th, and so will be out of view during the first week of the month.

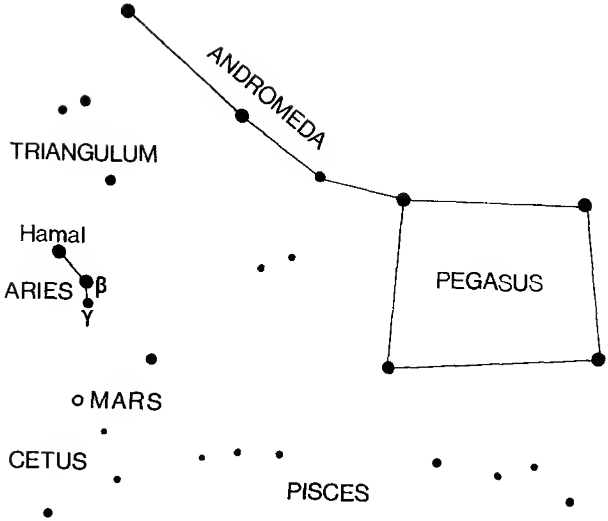
The Perseid shower officially begins on 27 July and ends on 17 August, though of course these dates are not definite. The radiant is on the borders of Perseus and Cassiopeia, about four degrees north of Gamma Persei; and the zenithal hourly rate or Z.H.R. is usually about 65. The meteors are generally bright, and frequently leave trails.

Of all annual showers the Perseids are the most reliable; they are not erratic, in the manner of the November Leonids, and they can always be depended upon to produce a good display. Records of them go back for more than a thousand years. They are thought to be associated with Comet Swift-Tuttle of 1862.

ARIES

This month Mars lies in Aries, a small group which is famous as being the first constellation of the Zodiac. Technically speaking it has long since lost this distinction; the vernal equinox has been shifted, by precession, into the adjacent group of Pisces, and so Aries should be regarded as the twelfth Zodiacal constellation instead of the first. However, the equinox is still known as the First Point of Aries.

Aries is not particularly bright, but it was listed by Ptolemy, and there is a mythological legend attached to it. It is said that Athamas, King of Thebes, had two children: Phryxus and Helle. The king's wife died, and Athamas married again; the new queen so ill-treated her stepchildren that the god Hermes (or Mercury) sent a ram with a golden fleece to rescue them. The ram could fly, and the children duly sat upon its back to be carried to safety. Helle slipped, and fell to her death in that part of the ocean still called the Hellespont. Phryxus held



on, and was carried to a friendly court. When the ram died, it was honoured with a place in the sky; the golden fleece was hung in a sacred grove from which it was later taken by Jason and the Argonauts.

Aries contains two stars above the third magnitude. Hamal (magnitude 2·0) is 76 light-years from us, and of spectral type K; Beta or Sheratan (2·7) is of type A5. Close to Sheratan is a fainter star, Mesartim or Gamma Arietis, which is a wide easy double with virtually equal components. The only other notable object in the constellation is the red long-period variable R Arietis, which can become reasonably bright even though it is never visible with the naked eye.

Hamal is easy to locate because there are no bright stars anywhere near it; bordering Aries are the faint constellations of Triangulum, Pisces and Cetus. Of course, at the present time the whole region is dominated by Mars, now brighter than any star in the sky visible during summertime and still increasing in brilliance as it approaches opposition.

September

Full Moon: 12 September *New Moon*: 26 September

Equinox: 23 September

Mercury is at superior conjunction on 2 September and remains invisible during the month.

Venus remains in the sky for about an hour after sunset, and now begins to grow a little brighter (magnitude −3·5 to −3·7).

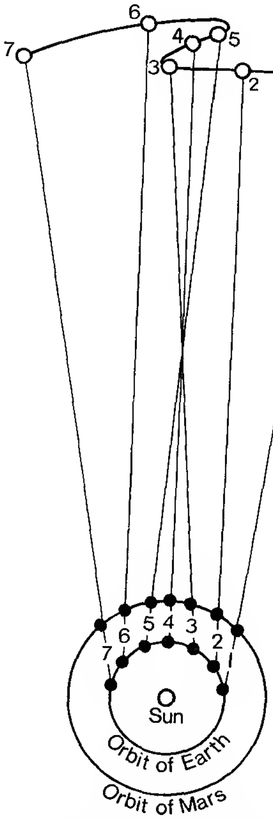
Mars now rises about an hour after sunset, and may be seen for most of the night in a dark sky. It is now a brilliant object (magnitude −1·2 to −1·9) and in this part of the sky there are no other bright stars nearby. Mars shows a marked slowing in its motion, and it comes to a stationary point on 19 September in Aries (see diagram in June notes), after which its motion becomes retrograde as it approaches opposition.

Jupiter also reaches a stationary point on 28 September in the western parts of Capricornus, and by then it will set at midnight. The planet is now fading again as it moves away from opposition (magnitude −2·3 to −2·2).

Saturn rises in the late evening and shows little change in brightness (magnitude +0·3). The planet is now moving direct on the western borders of Gemini and Taurus.

THE RETROGRADE MOVEMENTS OF PLANETS

After 19 September Mars will begin to move in a retrograde direction: that is to say, east to west against the stars instead of west to east. This behaviour is typical of all the superior planets, and presented great obstacles to the old Ptolemaic theory, according to which the planets moved round the Earth rather than the Sun. However, it is easy to explain, as the diagram shows.



Mars is further away from the Sun than we are, and moves more slowly. Therefore, the Earth 'catches Mars up' and passes it during the opposition period, and the planet seems to perform a kind of loop in the sky. The retrograde motion will continue until the end of November, after which the planet will resume its west-to-east march. Jupiter has also been retrograding, but reaches its second stationary point on 28 September, after which the motion will again be direct.

CENTENARY OF TWO COMETARY ASTRONOMERS

Giovanni Battista Donati, a famous Italian observer, died one hundred years ago, on 20 September 1873. He was born at Pisa in 1826, and after graduating from University he became an assistant at the Observatory of Florence; in 1859 he became Director. He was one of the first to apply the spectroscope to the stars, and carried out various important researches in the field of astrophysics, but he is remembered today chiefly because of his association with comets. In 1864 he studied Tempel's Comet, and formed a very accurate idea of its nature. From Florence he went to Arcetri, where he died — still active in astronomical research until the very end of his life.

On 2 June 1858, at Florence, Donati discovered a faint, misty object near the star Lambda Leonis. It was certainly a comet, but was a long way from the Earth – about 240,000,000 miles. As it approached, it brightened; by August it was visible with the naked eye, and had started to develop a tail. On 17 September the head had attained the second magnitude, and when at its closest to the Earth, during the second week in October, it was a superb object. There have been brighter comets (those of 1811 and 1843, for instance) but for sheer beauty Donati's has probably never been surpassed. In addition to the main tail, which was gracefully curved, there were two others, almost tangential. The comet moved southward, and was not seen in Europe after the end of October, but observatories in the southern hemisphere were able to follow it into the following spring. The last glimpse of it was obtained by Maclear, at the Cape of Good Hope, on 4 March, 1859.

No doubt Donati's Comet moves in an elliptical orbit, but its period is immensely long. Various mathematicians made estimates; Stampfer gave 2138 years, Löwy 2040, von Asten 1879, and so on. All these are probably under-estimates. There can be no hope of finding a reliable period for a comet whose path is so nearly parabolic. In any case, we may be sure that Donati's Comet will not be seen again in our time; there can now be nobody living who remembers it, and, sadly, this was before the days of useful astronomical photography. Yet judging from the eye-witness reports, and the many drawings made of it, it must have been a sight unrivalled in the history of cometary astronomy.

According to G. P. Bond, the values for the diameter of the nucleus and the length of the main tail were as follows:

	Diameter of nucleus		Length of tail	
Date, 1858	seconds of arc	miles	degrees	miles
July 19	5	5600	—	—
Aug. 30	6	4660	2	14,000,000
Sept. 8	3	1980	4	16,000,000
Sept. 23	3	1280	5	12,000,000
Oct. 5	1·5	400	33	33,000,000
Oct. 10	2·5	630	60	51,000,000

Martin Hoek, also famous for his cometary research, died at about the same time: 4 September 1873. He was born at The Hague in 1834, and after graduating from Leyden became professor of astronomy at Utrecht in 1859. He was the first to find that there are 'comet families'; for instance, many comets of short period have their aphelia at about the distance of Jupiter from the Sun, and this can hardly be a coincidence. It used to be thought that there were similar families associated with Saturn, Uranus and Neptune, though these are much less definite than in the case of Jupiter.

PISCIS AUSTRINUS

This is the best time of the year for finding the constellation of Piscis Austrinus (sometimes called Piscis Australis), the Southern Fish. Though one of the ancient groups, there seem to be no mythological legends attached to it, and in fact there is only one notable object: the first-magnitude star Fomalhaut.

To find Fomalhaut, use two stars of the Square of Pegasus (Scheat and Markab) as pointers. The direction-line passes through the barren regions of Pisces and Aquarius, and will pass very near Fomalhaut, which is so isolated that it cannot be mistaken – even though it is always low even as seen from Southern England, and from North Scotland it barely rises above the horizon.

Fomalhaut is 13 times as luminous as the Sun, and is of spectral type A. It is therefore very far from being a giant star, and owes its prominence to the fact that it is one of our nearer neighbours; its distance is a mere 24 light-years. Of the first-magnitude stars only Alpha Centauri, Sirius, Procyon and Altair are closer.

The Southern Fish contains no other stars as bright as the fourth magnitude, and neither are there any interesting telescopic objects, though Beta, Gamma and Delta all have faint companions. However, it is always satisfying to locate Fomalhaut itself, which is much the most southerly of the first-magnitude stars ever to be visible from the latitude of Greenwich.

October

Full Moon: 12 October *New Moon*: 26 October

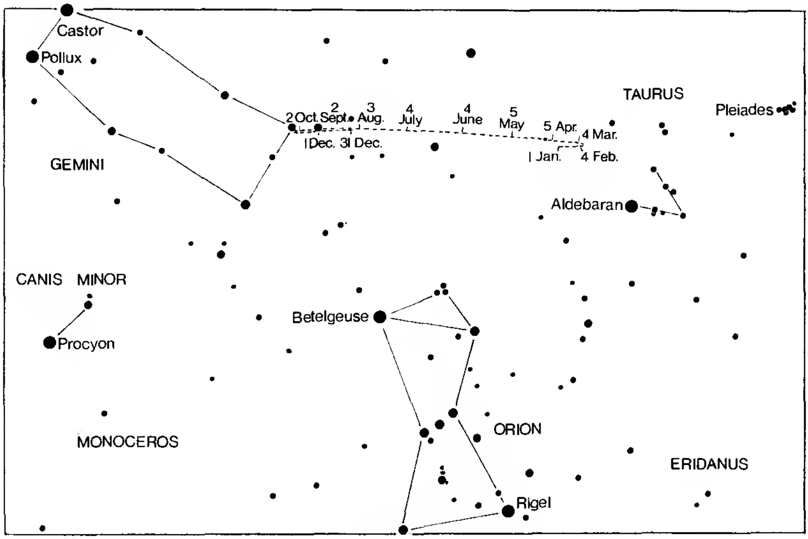
Mercury is at greatest eastern elongation on 18 October (25°), but is then badly placed and will be too low in the sky at sunset to be readily observed.

Venus continues to grow brighter (magnitude −3·7 to −3·9) and by the end of October it sets about two hours after the Sun.

Mars is at opposition on 25 October when it will be seen in the south at midnight on the borders of Aries and Pisces. At opposition, Mars is actually brighter than Jupiter (Mars −2·3, Jupiter −2·0). Because of the eccentric nature of its orbit, Mars will be at its closest to the Earth (40 million miles, 65 million km) on the night of 17 October. Although this is not such a close approach as in 1971, the planet is higher in the sky, and this is a very favourable opportunity to study the planet with large instruments. As in 1971, the south pole of the planet is turned towards the Earth.

Jupiter sets in the south-west before midnight and continues to fade during the month (magnitude −2·2 to −2·0). It is still a conspicuous object in Capricornus – one of the four bright planets which are now to be seen in the night sky.

Saturn is a morning star in Gemini and will be seen in the south at dawn. It is now a little brighter (magnitude +0·2 to +0·1) and after reaching a stationary point on 17 October, it begins its retrograde movement as it nears opposition in December. The diagram shows its position at this time on the western borders of Gemini.



Saturn, 1973

MARS AT OPPOSITION

Throughout October of this year Mars will be splendidly placed for observation. The maximum apparent diameter is 21·4 seconds of arc, as against 24·9 seconds of arc in August 1971 – when the planet was admittedly five million miles closer to us, but was inconveniently far south in the sky from the viewpoint of European and United States observers.

A small telescope will show the main dark markings, such as the Syrtis Major, the Sinus Sabæus, and the Mare Sirenum.

The Mariner results obtained from Mars in 1971-2 are described in the article by H. G. Miles. With a telescope, however large, do not expect to see the craters – but it is fascinating to reflect how much we now know about the fine structure of the various patches on the planet. Around opposition the polar cap should still be visible, though it will be small.

After opposition in 1971 Mars was veiled by a tremendous dustcloud, which was still present when Mariner arrived in the neighbourhood of the planet in November of that year. Whether we will see a comparable dust-storm in 1973 remains to be decided, but on the whole it seems that storms such as those of 1971, 1924 and 1909 (all perihelic oppositions) were very exceptional.

LUNIK 3

Fourteen years ago, in October 1959, the Russian vehicle Lunik 3 went round the Moon, and sent back the first photographs of the far side, always turned away from Earth. Two earlier probes in 1959 had been sent to the Moon, but Lunik 3 – sometimes nowadays referred to as Luna 3 – was the first to send back photographic results.

The Moon's far side had always been very much of a mystery. Because the lunar rotation is 'captured', the rotation period is exactly equal to the period of revolution round the Earth (27·3 days). There is no mystery about this; tidal friction over the ages has been responsible, but it meant that nobody had any real idea of the topography of the averted hemisphere. To be precise, libration effects mean that slightly more than half of the total surface can be examined from Earth at one time or another. 59 per cent is available, while 41 per cent can never be seen. Of course, features near the limb are highly foreshortened, and to map them accurately had always been a difficult matter.

Lunik 3 was launched on 4 October 1959, two years after the epoch-making flight of Sputnik 1. When on the Moon's far side, at a distance of about 35,000 miles from the lunar surface, photographs were taken; and when the probe returned to the neighbourhood of the Earth the pictures were transmitted. Judged by the standards of 1973 the Lunik 3 pictures are very primitive and blurred, but in 1959 they represented a tremendous technical triumph.

Various features were shown, and were given names; among them was the great dark-floored crater now known as Tsiolkovskii, in honour of the great Russian pioneer of theoretical space-flight. Another important feature was Giordano Bruno, the ray-crater. However, the Soviet authorities also believed that the photographs showed a major mountain range – later found to be nothing more significant than a bright ray, so that the "Soviet Mountains" have been erased from the lunar maps!

The eventual fate of Lunik 3 is unknown. It was hoped to re-run the pictures during its second orbit of the Earth, but all signals from it ceased abruptly, and were never resumed. At the time it was suggested that the probe had been hit by a meteorite, but it seems, on the whole, more likely that a fault developed in the transmitter. In any case, Lunik 3 had done its work well.

EJNAR HERTZSPRUNG AND THE H-R DIAGRAM

The late Ejnar Hertzsprung, one of the most distinguished of all Danish astronomers, was born at Frederiksberg, near Copenhagen, on 8 October 1873. During his long life he made many important contributions to astrophysics, and he remained active until the time of his death at the age of 96.

Hertzsprung's greatest contribution was the realization that stars of late spectral type (notably K and M) could be divided into two distinct classes, giants and dwarfs. Thus both Betelgeux in Orion and our nearest neighbour, Proxima Centauri, are of type M; but there is little resemblance between them, except that their surface temperatures and colours are approximately equal. Betelgeux is a huge giant, thousands of times more luminous than the Sun, and with a diameter of 250,000,000 miles; Proxima is a glow-worm by stellar standards. The giant and dwarf division is also marked for stars of solar type (G); thus the Sun itself is a dwarf, while Capella, also of type G, is a giant 200 times as powerful.

Hertzsprung's first papers on the subject were published in 1905, but for some time their immense significance was not realized. Later, H. N. Russell in the United States came to similar conclusions, and the eventual result was the production of a diagram in which the stars were plotted according to their spectral types and their luminosities. Diagrams of this kind are known as Hertzsprung-Russell or H-R Diagrams. Most of the stars fell along the line of the so-called Main Sequence, ranging from hot white or bluish stars (types B and A) through yellow (F and G), orange (K) and reddish (M). The giant branch is quite distinct, and so are the curious, highly-evolved stars known as White Dwarfs, which were unknown when the first H-R Diagrams were drawn up. (See the article by Iain Nicolson, p. 170).

H-R Diagrams are all-important in the field of stellar evolution, though the situation is much less straightforward than used to be thought when the giant and dwarf division was first recognized. Hertzsprung himself had much to do with the development of theoretical astrophysics; he paid special attention to Cepheid variables, and he made many other investigations. From 1935 until his retirement he was Director of the Leyden Observatory in Holland.

November

Full Moon: 10 November *New Moon*: 24 November

Mercury is in inferior conjunction with the Sun on 10 November, and on this occasion it will be seen in transit across the face of the Sun (see note below). Mercury is at greatest western elongation on 27 November, and there is then a chance of seeing the planet a few degrees above the horizon in the south-east before sunrise.

Venus is at greatest eastern elongation (47°) on 13 November. This is not a very favourable elongation, for although the planet is quite brilliant (magnitude −4·0 to −4·2) it is far south of the equator in Sagittarius and therefore low in the evening sky. After the first week of November, when Venus has a declination of 27° South, the planet begins to move north again and sets later each evening. By the end of the month it will be visible for three hours after sunset.

Mars is visible for most of the night, but fades rapidly as it recedes from the Earth (magnitude −2·1 to −1·2). The planet has a retrograde motion which carries it into Pisces, but it reaches a stationary point on 27 November, and after this moves direct again. The planet crosses the ecliptic on 25 November, and it is this proximity of the date of opposition to the passage through the ascending node that accounts for the peculiar S-shaped path of the planet at this time (see diagram in June notes). It is more common for opposition to occur at some distance from the node, and the path then shows a characteristic loop.

Jupiter is an evening star visible for a few hours after sunset in the south-west, and setting in mid-evening. The planet has now faded to magnitude −1·7.

Saturn rises north of east in mid-evening, and is now growing much brighter as it nears opposition (magnitude +0·1 to −0·2). The planet is moving retrograde in Gemini and will be seen close to the gibbous Moon on the night of 13 November. The rings are now open at their widest and the south side is presented to the Earth.

A transit of Mercury on 10 November begins at $7^{h}\ 49^{m}$ and ends at $13^{h}\ 17^{m}$ G.M.T., the times being the same, within about a minute, for all observers. The transit is visible in its entirety in Africa and Europe, including England and southern Scotland. In Ireland and the more northerly parts of Scotland, the transit will already have begun when the Sun rises. Only the end of the transit will be seen in the eastern parts of the United States and Canada.

Because the orbit of Mercury is inclined at 70° to the ecliptic, the planet normally passes well north or south of the Sun at inferior conjunction, but if this conjunction occurs when the planet is near one of the nodes of its orbit, a transit across the face of the Sun is possible. The ascending node of Mercury's orbit (where the planet crosses the ecliptic on its journey northwards) lies in longitude 48°, and the Earth is in this longitude on 10 November, and at the descending node on 9 May. These are the dates on which a transit of Mercury is possible, but because the Sun presents a sizeable disk of about half a degree in diameter, there is a certain range in the dates of inferior conjunction which will still allow the planet to be seen somewhere on the solar disk. This range is much greater in November (7/9 days) than in May (3/7 days) because of the eccentric nature of the orbit of Mercury. As a result there are more November transits than May ones; in the present century there are only four May transits (the last in 1970) as compared with ten in November.

On 10 November this year, inferior conjunction of Mercury occurs at $10^{h}\ 32^{m}$, while the nodal passage takes place only 31 minutes later. This transit is therefore almost central, the path of the planet crossing the Sun just south of the centre of the disk, and Mercury will be seen to move slowly along this line, which slopes upwards from east to west. Because both the Earth and Mercury are moving in the same direction round the Sun, the apparent motion of Mercury is quite slow and the transit lasts for 5½ hours. The tiny black dot, which is all that can be seen of Mercury, is best viewed by projecting the image of the Sun formed by a small telescope on a white card. *On no account should the Sun be viewed direct through the telescope.*

THE JUPITER PROBE

Pioneer F, the first attempt at sending a probe to Jupiter, was launched in March 1972. According to schedule, it should by-pass the Giant Planet toward the end of 1973; and if all goes well it should send back invaluable information.

Jupiter is utterly unlike the Earth, as is described by G. E. Satterthwaite in the Article section of this *Yearbook*. There is much that we do not know about it; for instance, what is the precise nature of the Great Red Spot, which has been under observation for so long, and yet which still remains very much of an enigma? In fact, we can hardly hope for spectacular pictures from Pioneer, even if it arrives safely; but the various experiments carried should go at least some way to solving the outstanding problems.

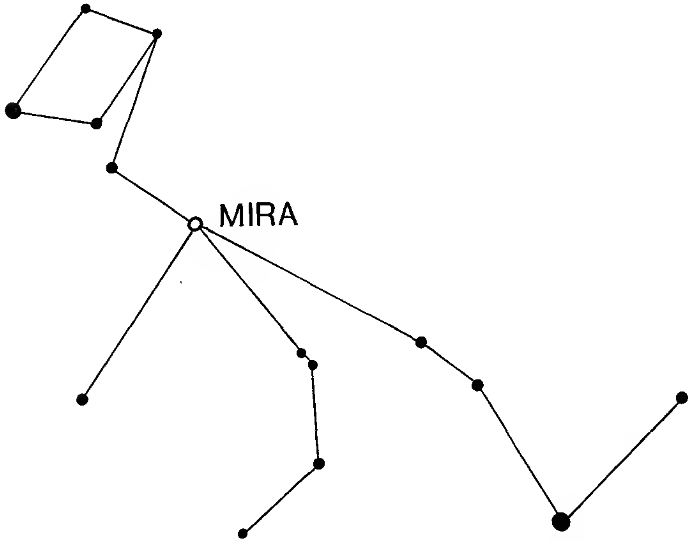
First, however, Pioneer has to pass through the asteroid belt. It may well be that the dangers of this region of the Solar System have been exaggerated, but it is true to say that we have no knowledge of many of the smaller members of the asteroid swarm – and in any collision, Pioneer would certainly emerge second best! A mishap of this sort would mean a sudden and permanent loss of communication. All we can really do is hope for the best.

After by-passing Jupiter, Pioneer will be moving so quickly that it will escape from the Sun's grip altogether, and will move off into interstellar space. With more hope than expectation, the space authorities have enclosed a plaque showing two human figures, together with a diagram showing the position in the Solar System from which the probe was launched. The chances of this ever being examined by extra-terrestrial beings seem, however, to be small, to put it mildly.

These words are being written in March 1972. By November 1973 we will know whether Pioneer F has succeeded or not; and we will also know what has happened to the identical probe Pioneer G, scheduled to be launched earlier in 1973.

MIRA CETI

Probably the most famous variable star in the sky is Mira, or Omicron Ceti. It is shown in the diagram below, and is visible with a modest telescope. At times it is a conspicuous naked-eye object, and has been known to attain the first magnitude, though such occasions are rare.



Mira is a long-period variable, with a mean period of 331 days; this is a good average, though, as with all stars of this kind, both the period and the amplitude are subject to fluctuation. Obviously, the star will come to maximum about a month earlier in each year. There was a maximum in May 1972, and another in April 1973; the next is due in March 1974. This means that during the winter of 1973-4 Mira is near its minimum, and special charts are needed to locate it. When maximum occurs in the high summer, Mira is practically unobservable, because it is too near the Sun in the sky.

Another long-period star which can become visible with the naked eye is U Orionis. The maximum magnitude never exceeds 5, so that there is no real comparison with Mira; but the period is 372 days, so that maxima occur only about a week later each year. At present they take place in the summer, when the star is above the horizon only during daylight – and it will be well into the 1980s before U Orionis will again be visible with the naked eye against a dark background.

All variables of Mira type are Red Giants, well advanced in their evolutionary careers. They are genuinely variable in output – in contrast with the eclipsing binaries such as Algol in Perseus, which are not truly variable at all.

December

Full Moon: 10 December *New Moon*: 24 December

Solstice: 22 December

Mercury is theoretically a morning star, and although it may possibly be glimpsed in the first few days of December, it will remain too near the Sun to be seen for the rest of the month.

Venus is at greatest brilliancy (magnitude −4·4) on 19 December, when it sets more than three hours after the Sun. The planet is still rather low in the south-west, but this will be the best opportunity to see this planet during the year. At the end of December Venus and Jupiter are together in the same part of the sky, but Venus moves rapidly to inferior conjunction before the two planets are at their closest.

Mars is an evening star, to be seen in the south in the early evening and setting about 3h. at the end of the month. The planet fades by a whole magnitude (−1·2 to −0·2) as its distance from the Earth rapidly increases. Mars is moving direct and at the end of December it passes again into Aries.

Jupiter now sets in the south-west about three hours after the Sun, and fades during the month to magnitude −1·6. At the end of the year Venus and Jupiter will be seen only two or three degrees apart, but Venus will be about ten times as bright as Jupiter.

Saturn is at opposition on 23 December on the borders of Gemini and Taurus. Its magnitude at this time is −0·3 and its distance from the Earth about 747 million miles (1200 million km).

A partial eclipse of the Moon on 10 December will be visible in Europe and America. The eclipse begins at $1^h\ 09^m$ and lasts until $2^h\ 20^m$ about 11 per cent of the Moon's disk being covered by the Earth's shadow at $1^h\ 45^m$ (See notes on page 114).

An annular eclipse of the Sun on 24 December will be visible as a partial eclipse in the British Isles just before sunset, and in the eastern parts of North America shortly after sunrise. (See notes on page 114).

VENUS AT ITS BRIGHTEST

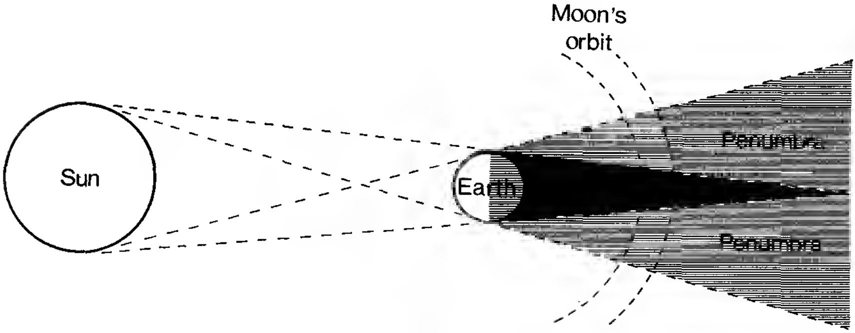
Though Venus is low in the sky this winter, it is still much brighter than any other star or planet; and during the week before Christmas it will be at its best. Inevitably, there will be the usual inquiries as to whether Venus could have been the Biblical Star of Bethlehem. Spectacular though it may be, the answer can only be 'No'. According to the Biblical account, the Star was something distinctly unusual – and if the Wise Men were deceived by a perfectly normal appearance of Venus, they can hardly have been very wise!

Telescopically, Venus shows up this month as a crescent. This may seem surprising in view of the fact that it is at its greatest brilliancy, but there is a simple explanation. As Venus moves closer to the Earth, the phase decreases; when it is at its nearest – at inferior conjunction – it is approximately between the Earth and the Sun, so that it is new, and cannot be seen at all. But though the phase shrinks, the apparent diameter increases, and this is more than enough to compensate. Therefore Venus is always at its brightest when in the crescent stage, as during this month.

At the end of the month it will be interesting to compare Venus with Jupiter. Admittedly, Jupiter is now half a magnitude fainter than it used to be earlier in the year, but the contrast is very pronounced. Moreover, the albedo or reflecting power of Venus is greater than that of Jupiter.

ECLIPSES OF THE MOON

Most people know the theory of a lunar eclipse. The Moon passes into the cone of shadow cast by the Earth, and turns a dim, sometimes coppery colour until it emerges. The principal cone of shadow, known as the umbra, is 860,000 miles long on average; this is more than three times the distance of the Moon from the Earth, so that at the mean distance of the Moon (239,000 miles) the cone has a diameter of about 5,700 miles. Totality may last for as much as 1¾ hours; the Moon, remember, moves across the sky at an hourly rate which allows it to cover slightly more than its own apparent diameter. During an eclipse the Moon does not vanish entirely, because some of the solar rays are refracted on to it by way of the Earth's shell of atmosphere.



Solar Eclipse

Because the Sun is a disk rather than a point source, the umbra is bordered by an area of penumbra or 'partial shadow'. Obviously, the Moon has to pass through the penumbra before entering the umbra, and the diminution in light can sometimes be enough to be detected visually by an experienced observer.

Lunar eclipses have been recorded ever since early days in human history. The first reliable report comes from China, in 1136 B.C. The colour effects are sometimes glorious, but everything depends on the state of the Earth's atmosphere, through which the Sun's rays have to pass before reaching the eclipsed Moon. For instance, the eclipse of 1761 was so 'dark' that according to the Swedish astronomer Per Wargentin, no trace of the Moon could be seen even through a telescope.

During a lunar eclipse, the lunar surface becomes intensely cold. It has been found that some localized regions, such as the great ray-crater Tycho, cool down less rapidly than their surroundings and these regions have received the rather misleading nickname of 'hot spots'.

This month's eclipse of the Moon is not spectacular, in that only 11 per cent of the lunar surface will be in shadow; the eclipse is not total from anywhere on Earth, since, unlike solar eclipses, the phases of lunar eclipses do not depend upon the observer's geographical locality. If the Moon is above the horizon during an eclipse, then the eclipse will be seen – clouds permitting!

It may be useful to list future lunar eclipses from now until 1978:

(*a*) *Visible from Greenwich*

1974 June 4,	mid-eclipse	22.14	G.M.T.	80 per cent. eclipse
1975 Nov. 18,	„	22.24	„	Total
1976 May 13,	„	19.50	„	10 per cent Moon rises eclipsed
1977 April 4,	„	04.21	„	20 per cent. Moon sets eclipsed
1978 Sept. 16,	„	19.03	„	Total Moon rises eclipsed

(*b*) *Visible from the United States*

1975 May 25,	mid-eclipse	05.46	„	Total
1975 Nov. 18,	„	22.24	„	Total
1977 April 4,	„	04.21	„	20 per cent.

It used to be thought that the sudden cooling might produce observable changes in certain lunar features, but the evidence is extremely slender, and no certain effects have ever been established. However, observers of the Moon will be interested to watch the eclipse this month – even though its magnitude is so small.

The Return of Orion

As the year draws to its end, Orion reappears in the evening sky. Apart from Ursa Major, the Great Bear, it is the most familiar of all constellations; and since it is crossed by the celestial equator, it is visible from all over the Earth – whereas Australians and New Zealanders can never see the Bear, while New Yorkers and Londoners can never see the Southern Cross.

So far as small telescopes are concerned, the most spectacular object in Orion is the Great Nebula, Messier 42; but there are many rich star-fields, and the Milky Way runs nearby. As a 'direction-finder' Orion is invaluable.

Below Orion lies the relatively small and obscure constellation of Lepus, the Hare; the most notable object is the 'Crimson Star' R Leporis, which, like many very red stars of late spectral type, is a long-period variable. At its maximum it is just visible with the naked eye, though during this winter binoculars will be needed to show it. In fact R Leporis is a star of the same kind as Mira, and appears so much fainter only because it is much further away from us. Later in the night Orion will be high in the south, and will be visible in its full glory together with its retinue – including Sirius, which shines as the brightest star in the entire sky.

Eclipses in 1973

In 1973 there are four eclipses, three of the Sun and one of the Moon; there are also three penumbral eclipses of the Moon.

(1) *An annular eclipse of the Sun* on 4 January, the central track extending from the extreme south of South America across the southern Atlantic Ocean. Visible as a partial eclipse in South America and parts of West and South Africa.

(2) *A total eclipse of the Sun* on 30 June of duration 7 min. 04 sec. The line of totality crosses the North Atlantic Ocean from Guyana to the west coast of Africa, about 350 miles north of Dakar, and extends from Guinea through Nigeria to Kenya, ending in the Indian Ocean.

This very favourable eclipse belongs to the same series as the 19 May, 1919 eclipse when tests of Einstein's Theory of Relativity were made from the island of Principe. A partial eclipse will be visible throughout most of Africa and south and west Europe. In the extreme south-west of England a small partial eclipse will be seen. At Penzance it will begin at 10^h44^m G.M.T. and at maximum about 6 per cent of the Sun's disk will be covered at $11^h\,08^m$ G.M.T.

(3) *A partial eclipse of the Moon* on 10 December will be visible in Europe, Africa and the Americas. The eclipse begins at $1^h\,09^m$ G.M.T. and ends at $2^h\,20^m$, about 11 per cent of the Moon's disk being covered by the Earth's shadow at $1^h\,45^m$.

(4) *An annular eclipse of the Sun* on 24 December, the path crossing the northern parts of South America and the North Atlantic Ocean to end in northern Africa. Visible as a partial eclipse in South America, the eastern and southern parts of North America, south and west Europe.

In the British Isles the eclipse begins shortly before sunset. In latitude 52° the eclipse begins at $15^h\ 21^m$ G.M.T., but sunset occurs at $15^h\ 52^m$, before the maximum phase (40 per cent) is reached.

In the eastern parts of North America the eclipse takes place in the morning, about two hours after sunrise, but the times vary widely with the latitude and longitude of the observer. The following are some typical times (G.M.T.):

	Begins	Maximum	
Washington D.C.	13h. 00m.	14h. 04m.	(23 per cent)
New York	13h. 12m.	14h. 10m.	(19 per cent)
Montreal	13h. 30m.	14h. 17m.	(12 per cent)

Three penumbral eclipses of the Moon are predicted for 18 January, 15 June and 15 July, but the loss of light when the Full Moon is obscured by the penumbra of the Earth's shadow is so slight that the phenomenon is not normally observable without special equipment.

The Southern Skies

In this *Yearbook*, the star maps are, inevitably, drawn for observers in the northern hemisphere. Maps for observers who live in Australia, New Zealand and South Africa would be different; of course, many of the constellations are visible from all parts of the world (Orion, for example), but people who live in the south lack the Great Bear, just as Britons and New Yorkers can never see the Southern Cross.

An article on the southern stars was given in the *1972 Yearbook*, and the notes which follow here are intended only as a general guide. Details of eclipses and other phenomena are given in the monthly notes for southern observers as well as for northern.

In summer (December) evenings Orion is splendid in the north-east; Sirius shines brilliantly, and Canopus is high up, seeming almost to rival Sirius in glory. Achernar, the first-magnitude leader of Eridanus, is almost overhead; to the north-west the Square of Pegasus may be made out, and Fomalhaut is higher in the north-west, appearing much more striking than Europeans can realize. Crux Australis, the Southern Cross, is low in the south – at least from South Africa and most of Australia; from New Zealand it always maintains a respectable altitude. The Clouds of Magellan are high, and so is the characteristic constellation of Grus, the Crane.

In autumn (March) evenings Orion is still very evident, and Crux is becoming prominent in the south-east. South Africans and most Australians – though not New Zealanders – will see Capella shining low over the northern horizon; Fomalhaut is nearing the horizon in the south-west. By winter (June) evenings Crux is near the zenith, with its two glorious 'pointers', Alpha and Beta Centauri; Orion has gone and Achernar is low, while Antares in the Scorpion is climbing in the south-east, and Leo and Virgo are quite high in the northern part of the sky. Sirius is low, but Canopus is still dominant, south-west of the zenith, together with the gloriously rich region of Carina, the

Keel of the now-dismembered Ship Argo. By the end of July Jupiter, at opposition in Sagittarius, is at its best – due north at midnight; and it remains high and prominent throughout evenings in spring (September), when the Scorpion, too, is magnificent, and near the zenith. Crux is now in the south-west, but still conspicuous. Later in the evening the triangle comprising Vega, Altair, and Deneb may be seen in the north, though only Altair is reasonably high. Mars, at opposition at the end of October, is near the celestial equator, so that it is just as well seen this year from the southern hemisphere as from the north.

Occultations in 1973

In the course of its journey round the sky each month, the Moon passes in front of all the stars in its path and the timing of these occultations is useful in fixing the position and motion of the Moon. The Moon's orbit is tilted at more than five degrees to the ecliptic, but it is not fixed in space. It twists steadily westwards at a rate of about twenty degrees a year, a complete revolution taking 18·6 years, during which time all the stars that lie within about six and a half degrees of the ecliptic will be occulted. The occultations of any one star continue month after month until the Moon's path has twisted away from the star but only a few of these occultations will be visible at any one place in hours of darkness.

There are only four first magnitude stars that can be occulted by the Moon; these are Regulus, Aldebaran, Spica and Antares.

During 1973 the Moon's path lies entirely clear of these bright stars, so that none of them is occulted during the year. The planets Mercury, Mars, Jupiter and Saturn will all undergo occultations during the year, but none of these events is visible in the British Isles.

Comets in 1973

The appearance of a bright comet is a rare event which can never be predicted in advance, because this class of object travels round the Sun in an enormous orbit with a period which may well be many thousands of years. There are therefore no previous records of the previous appearance of these bodies, and we are unable to follow their wanderings through space. The comets of short period, on the other hand, return at regular intervals, and attract a good deal of attention from astronomers. Unfortunately they are all faint objects, and are recovered and followed by photographic methods using large telescopes. Most of these short-period comets travel in orbits of small inclination which reach out to the orbit of Jupiter, and it is this planet which is mainly responsible for the severe perturbations which many of these comets undergo. Unlike the planets, comets may be seen in any part of the sky, but since their distances from the earth are similar to those of the planets their apparent movements in the sky are also somewhat similar, and some of them may be followed for long periods of time.

The following short period comets are among those most likely to be recovered in 1973:

Comet Tuttle-Giacobini-Kresák has the short period of 5½ years, and was first seen in 1858 and again for eleven days in 1907. It was not seen again until 1951, and it is these three independent discoveries that have given rise to the triple name. Although the comet was not seen in 1967, a good orbit is available, since the comet was followed for several months in 1962.

Comet Brooks (2) was last seen in 1960 but was badly placed in 1967. This faint comet was discovered in 1889, and has been seen at ten returns. The past history of the comet is interesting, as it has been shown that it made a very close approach to Jupiter in 1886, the resulting perturbations having reduced its original period of 29 years to the present value of 7 years. In

1973 the passage through perihelion occurs at the end of the year.

Comet Reinmuth (1) is expected to return in the spring. It was discovered in 1928 and seen at subsequent returns in 1935, 1950, 1958 and 1965. It was badly placed at this last return and only a few observations were made, but conditions are much more favourable in 1973. This comet has a period of 7.6 years and its orbit lies outside the orbit of Mars.

Comet Kearns-Kwee was discovered in 1963 on plates taken with the 48-inch Schmidt telescope at Mount Palomar. It has a period of about nine years and the whole orbit lies outside that of Mars. The comet was followed for a long period from 1963 into 1965, and it should be recovered before the end of 1972. Research has shown that the comet also made a close approach to Jupiter in 1961, with the result that the period was reduced from 51 years to the present value.

Comet Wild, discovered at Bern in 1960, has a much longer period of 13 years so that the orbit, which is inclined to the ecliptic at an angle of 20°, reaches out to the distance of Saturn. Comet Wild is a faint object, but it was followed for about two months in 1960, and is expected to return to the Sun early in 1973.

Comet Schwassmann-Wachmann (1) has a nearly circular orbit with a period of 16 years, which lies entirely between the orbits of Jupiter and Saturn. It behaves very much like a planet and is visible each year. This comet is remarkable because it undergoes changes of brightness, which seem to have some connection with solar activity.

Meteors in 1973

Meteors ('shooting stars') may be seen on any clear moonless night, but on certain nights of the year their number increases noticeably. This occurs when the Earth chances to intersect the orbit of a meteor swarm, which is a concentration of meteoric dust moving in an orbit around the Sun. Such an intersection can occur only at one particular time of year, but if the dust is spread out along the orbit, the resulting shower of meteors may last for several days. The word 'shower' must not be misinterpreted – only on very rare occasions have the meteors fallen so fast as to resemble snowflakes falling.

The naked-eye study of meteors is quite a laborious task, but even a casual observer, watching for, say, ten minutes on an August night, may observe a number of Perseids. If their tracks are marked on a star map, and traced backwards, a number of them will be found to intersect in a point (or a small area of the sky) which marks the radiant of the shower. This gives the direction from which the meteors have come.

The following table gives some of the more easily observed showers with their radiants; the effect of moonlight in 1973 is indicated.

Limiting dates	*Shower*	*Maximum*	*R.A.*	*Dec.*	*Range*
Jan. 1-4	Quadrantids	Jan. 3	$15^h 28^m$	+ 50°	
April 20-22	Lyrids	April 21	$18^h 08^m$	+ 32°	M
July 27-Aug. 17	Perseids	Aug. 12	$3^h 04^m$	+ 58°	M
Oct. 15-25	Orionids	Oct. 21	$6^h 24^m$	+ 15°	
Oct. 26-Nov. 16	Taurids	Nov. 1	$3^h 36^m$	+ 14°	
Nov. 15-17	Leonids	Nov. 17	$10^h 08^m$	+ 22°	M
Dec. 9-14	Geminids	Dec. 14	$7^h 28^m$	+ 32°	M
Dec. 17-24	Ursids	Dec. 22	$14^h 28^m$	+ 76°	

M = moonlight interferes

Minor Planets in 1973

Although there are many thousands of minor planets, only about 2,000 have well-determined orbits, and are listed in the catalogues. Of these, only the 'big four', Ceres, Pallas, Juno and Vesta can reach any considerable brightness; Vesta can occasionally be seen with the naked eye. In 1973, however, Vesta does not exceed magnitude 6·9 in January, and although Ceres may reach the same value, Pallas will not exceed magnitude 8·0, and Juno magnitude 10·0.

Some Events in 1974

ECLIPSES

In 1974 there will be four eclipses, two of the Sun and two of the Moon.

4 June – a partial eclipse of the Moon (83 per cent), visible throughout Europe.

20 June – a total eclipse of the Sun, visible only in the southern hemisphere.

29 November – a total eclipse of the Moon, visible in Asia and Australasia.

13 December – a partial eclipse of the Sun, visible in North America and the North Atlantic Ocean.

THE PLANETS

Mercury will be most easily seen as an evening star at greatest eastern elongation on 9 February, and as a morning star at western elongation on 10 November.

Venus is in inferior conjunction on 23 January, and reaches greatest brilliancy as a morning star on 27 February, and greatest elongation west on 4 April. Venus is in superior conjunction on 6 November.

Mars is an evening star for the greater part of the year, reaching conjunction with the Sun on 14 October. There is no opposition of Mars during the year.

Jupiter is in conjunction on 13 February, and comes to opposition on 5 September, when it will be in Aquarius.

Saturn is an evening star until conjunction on 30 June. There is no opposition of Saturn in 1974.

Uranus is at opposition in Virgo on 16 April.

Neptune is at opposition on 29 May in Scorpius.

Pluto is at opposition on 23 March.

PART TWO

Article Section

The general pattern of our Article Section follows closely on that adopted in previous *Yearbooks*. G. A. Hole contributes some useful practical hints on silvering the mirrors of reflectors; Howard Miles discusses the latest results obtained from Mariner 9 and the two Russian probes to Mars, and Gilbert Satterthwaite looks out toward the giant planet Jupiter. Henry Brinton offers a straightforward explanation of tidal phenomena, while we are delighted to include four astrophysical articles from four highly distinguished professional scientists: Iain Nicolson, David Allen, Simon Mitton and G. J. H. McCall. Biographical notes of our contributors will be found on page 232.

Silvering

G. A. HOLE

A telescope mirror without a silver or aluminium film on its surface reflects only 4 per cent of the light falling on it. To increase this to usable proportions the film is necessary, and aluminium has these days replaced silver for this purpose. It has certain very definite advantages, mainly in being much tougher and thus not demanding the cosseting that is essential for a silver film to remain serviceable. If the aluminium film does receive this cosseting, it has a very long life indeed, providing it was properly put on in the first place. I have been told by a very well-known commercial firm who do a lot of this work for me that they consider two years a reasonable life for a film. This may be so, for an unprotected surface, but if kept covered and protected from condensation it will last for double or treble this time. And so will silver. However, if a silver film is not protected it will become useless in weeks; and if allowed to get damp, in hours.

So, on the face of it, aluminium has an undeniable advantage over silver and, if given an extra coat of transparent silica, should be impervious to exterior influences. If properly put on, it will be impervious to internal ones as well. However, a large proportion of aluminium films fail from chemical reaction originating from beneath the film, due to inadequate cleaning when the surface was being prepared. The degree of cleanliness needed to secure a good adherent coat is far harder to achieve for aluminium than for silver, due in part to the differing processes used for each metal. Silver can be deposited from a water bath, aluminium demands high vacuum equipment. A surface to be coated with aluminium has to be both clean and dry, one to be silvered has only to be clean.

What this amounts to is that a surface has a much tougher time being prepared for aluminizing than for silvering, and if it be an optical surface it can be very quickly degraded. That this is a very real hazard is proved by the fact that normal professional optical work produces, in my experience alone, at least one or two cases a year requiring complete refiguring. Assuming a similar intake for other optical firms, it adds up to quite a few spoiled mirrors.

There is also a cost question to consider. The use of paid specialist labour and very expensive equipment, with the carriage and transport charges involved in getting the job to them, amounts to at least a pound or two, with a delay of a week, often more, before the telescope is back in commission, as well as transport risk. These facts have often caused me to wonder at the almost universal way in which aluminium has replaced silver as a mirror coat among amateur observers. Silver, it is true, is delicate, and easily spoiled, but it is not hard to keep a silver film in good condition for several years, and it is so simple and cheap to replace a film, with no damage to the glass surface, that the owner can do it himself as often as he feels it necessary. Even a large mirror can be out of the telescope, recoated and back in use again in one day. I have critically tested mirrors that date from Calver's and With's days, that must have been re-coated dozens of times, and have found them, almost without exception, practically as the maker left them. One gets to know their fists. As, apart from durability, aluminium offers no advantage for visual use, its universal use may be perhaps attributed to lack of information as to how to silver a mirror.

The following materials have to be available. Nitrate of silver, liquid ammonia, caustic potash or caustic soda, dextrose, cotton wool, a gallon or two of distilled water, two 4-oz. measuring glasses and one larger one, 10 or 20 oz., a pair of scales, and a stirring rod. Also something to silver in, and, a luxury this, a pair of rubber gloves. A hair dryer to dry off the film quickly, and some chamois leather pads to polish it. Also some nitric acid for cleaning.

Nitrate of silver, chemically pure (C.P.) costs, in small quantities, about 70p. per oz. If bought in 4-oz. lots, from wholesale suppliers, cost is about 50p. per oz. One oz. will silver a 6-inch or 8-inch mirror four or five times at least. This is the only costly item used. Caustic potash (KOH) or caustic soda (NaOH) comes in pellet form. The soda is always cheaper than potash, and works just as well. A 4-oz. bottle, if kept airtight (the stuff is thirsty) will last a long time, and costs less than one pound. Also the dextrose. Proprietary brands, such as glucose D, work as well if the chemist has not the bulk material. A white powder, rather like dried milk to look at; again, quite inexpensive. Liquid ammonia, 0·880 a 4-oz. bottle. Cotton wool, best quality, a small roll. Concentrated nitric acid, for cleaning; an ounce or two.

Up to 12-inch diameter I find it not worth while to edge band the mirror and use it as its own dish. It is much less trouble to have a dish an inch or so larger than the mirror, and 6-inch or 7-inch deep made out of anything, hardboard base with lino walls, a circular tin, or any plastic item that is right for size. Whatever is used, coat it inside with melted paraffin wax to stop it affecting the solution.

Over 12-inch diameter it is best to make up an edge band, some 6-inch deep, that closely fits the mirror, and seal it in position with adhesive tape. The band can be made of lino, stiff paper of the Sisalkraft type, or roofing felt. I keep several made up of 'Bitumenised Damp Course', a thick 4½-inch wide strip that any builder's merchant can supply. If doubtful as to its water-retaining properties, pass it through a wax bath. When a closely fitting edge band has to be used it becomes slightly more difficult to clean the mirror right up to its margin, hence my preference for the separate dish.

The mirror must be cleaned very thoroughly. Place it on a couple of battens over a basin and pour on it a spoonful or so of the nitric acid, and, with rubber gloves on, take a piece of cotton wool (have four lumps detached and ready to hand) and rub it all over the surface very thoroughly, paying special attention to the margin. Swill off with clean tap water, then repeat the dose, and swill again with tap water, followed by distilled, to get rid of the tap water. Observe that no part of the surface dries, or refuses the water film. If it does, that part is still contaminated. If judged satisfactory, place the wet mirror in its dish, face up, and pour in distilled water until the surface is under water to a depth of an $\frac{1}{8}$-inch or so. It is then given a final clean through the protective water with a clean cotton wool tuft. Then it can wait while the solutions are mixed. I have never found any advantage from using stannous chloride as a cleaning agent.

Silver nitrate comes as small white crystals, so has to be dissolved, as does the potash or soda, and the dextrose. I normally dissolve 1 oz. of nitrate in 16 oz. of distilled water, producing a solution that contains 30 grains of silver per fluid oz. In brown stoppered-bottles it keeps indefinitely, and saves a weighing operation every time. Potash or soda do not keep well in solution, so they are better weighed and dissolved at the time of use. Treat dextrose the same way.

Now, quantities to use. These are not critical. Good films result when 2 grains per sq. in. of surface is taken as a base for calculation. A 6-inch mirror will have some 28 sq. ins. of surface and require 56 grains of silver. 60 grains is two fluid ozs. of stock solution, so 60 grains it is. Anything from 60 per cent. to equal quantity will do for the potash or soda. I have had good films with as low as 40 per cent. So, 45 grains is taken as potash required. To reduce these, dextrose is needed in the rate of 50 per cent. (or thereabout) of the weight of silver. So 30 grains of dextrose is the quantity.

The potash and dextrose take longest to dissolve, so they are weighed out, and each put in a separate glass with a couple of ounces of distilled water and put on one side to dissolve, stirring frequently. The potash will take a lot of stirring. While this is proceeding, measure out slightly less than the two ounces of silver solution, in the large glass. Then add, drop by drop, liquid ammonia. The solution will turn cloudy as the ammonia reacts with the silver. Continue to add ammonia, drop by drop, until the solution begins to clear again. It must not contain enough ammonia to clear it completely. Clear solution means excess of ammonia over silver, and in that condition it won't work. Stop the ammonia when the silver solution is still discoloured. If, as sometimes happens, despite stirring continuously while adding the ammonia, the silver clears up, add a drop or two of silver from the stock bottle. I took slightly less than the indicated amount to allow for this. Using this technique it is easy to get a clouded, tea-coloured solution, just short of full clearing up. Such a solution has silver in excess, and is what is wanted.

Take the now dissolved potash or soda, and add it slowly, little by little, stirring the while, to the silver/ammonia solution previously produced. The silver/ammonia solution at once turns black, and must be again ammoniated, just as before, until nearly cleared, but not quite. When the reserve silver is added, in the final stages, it hangs in a cloud on the surface, indicating that there is not an excess of ammonia present able to clear it. This is the required final state of the silver potash ammonia solution, that there should be an excess of silver. It doesn't matter if it is muddy, but it must not, repeat not, be clear.

Add the now dissolved dextrose solution to the keeping water over the mirror waiting in its dish. Pour in a few drops of the mixed silver solution (thus creating a very weak bath) and give the mirror surface a last rub over with a cotton wool pad through this 'live' water in case anything has settled on it while waiting. Then add the bulk of the prepared silver solution, and commence to rock the dish quite vigorously. This is in order to allow a really vigorous tidal wave of solution to form and be swirled all over and round the mirror, and for that the deep dish is needed.

The liquid changes colour from the original tea colour to very dark brown, and then begins to clear, with the formation of a flocculent mud, which means that the reaction is complete. During the duration of the reaction, which may vary from a minute to five or six, according to temperature, amount of reducer, accuracy of ammoniation, and other variables, the film of metallic silver is forming on the glass, and the vigorous swirling serves two purposes. The first and most important is to get as much as possible of the solution in contact with the glass during its brief 'live' existence. The second is to keep this mud or sediment moving, thus preventing it shielding the glass from the silver.

When the sediment flakes can be seen separately in the solution it is spent, and is tipped away. Rinse out with tap water (the silver film, unlike the original nitrate, being tolerant of this) to remove the mud; lift out the mirror and swill it off under the tap, washing off as much of the adhering sediment as the water jet will shift. A very light, trailing tail of cotton wool can be pulled across the wet film with no weight at all, to help this, but it is not essential, and as the wet film is very fragile, may be dangerous. Then stand the mirror on edge, leaning it against a suitable support as near vertical as is safe, and tuck a pinch of cotton wool under its lower edge to soak off the water as it drains. Apply the hair dryer and chase off the water with the hot air. At the last, remove the cotton-wool soaker and dry off that area, and see that no drops stay on the edge.

Then lay the mirror on its back, and dust off the surface with a bunch of cotton wool. Do not rub, just dust it. All the remaining sediment, now a dry dust, will come right off. At this stage the silver is cloudy and yellowish, as it still needs buffing. For this clean chamois leather pads stuffed with cotton wool, are used. A piece of soft chamois some 8-inches square is filled with cotton wool and pinched up into a pad about as big as a small orange. Keep the softer side out. Have it washed first to ensure that it is free from grease, then knead it inside a clean handkerchief to soften it.

Two of these pads are needed, one used plain, the other with powdered rouge. A blunt, clean knife is used to scrape off these pads every few seconds, to dislodge 'corns' of picked up silver, and prevent them scratching. Proceed thus. Dust off the mirror with cotton wool, and taking the plain pad, firmly place it on the film and rub a few strokes. Scrape off pad, even if you don't think it needs it, dust off again, and repeat. The film begins to look like silver at once. A few seconds of this and change to the second pad, which has been rouged by rubbing it on some rouge powder placed on a spare piece of chamois. Rub the pad on this, scrape it off with the knife, dust off the mirror, and a very few seconds of buffing will suffice to polish the film fully.

The whole operation of coating a mirror takes much less time than it does to write about it. The process described will without fail produce a successful bath, and if the mirror was clean, it will get a good share of the precipating silver in the vital initial stages before the sediment forms, and the silver comes down in a granular frosty form, which is what happens if a bath is left on too long. Such a film takes a lot of polishing.

Normal temperatures, about 60°F, are best, but it is always an advantage to have the mirror itself a few degrees warmer than the solution. It is so worth while that I always put a little heat in the glass by standing it on a wooden cross in the bottom of an enamel basin of cold water, and gently raise the water to blood heat while getting the other stuff ready. The keeping water, distilled, is gently warmed also, and some of it used for the cleaning. The reaction proceeds more positively, the mirror gets a better coat and the final polishing is free from condensation, as there is still some slight warmth in the glass. It can be done without warming, but is much more certain if done as described, and, as blood heat is enough, is quite without risk. Also, cold weather does not prevent the job being done. For large mirrors, the keeping water is warmed, and so the mirror. One is thus independent of the ambient temperature.

Having produced and polished the film, preserve it. This calls for a chamois leather pad the same size as the mirror, made by stretching a soft skin over a circle of hardboard, with a layer of cotton wool between board and skin. It should fit the mirror and have a lifting string on its back. It is the only thing that should ever touch the mirror and it lives permanently in contact with it except for actual observing periods.

The mirror and its pad should be inside a cell with walls an inch or so higher than the mirror surface. This cell should have a cover like a toffee-tin lid, but not too tight. Given this protection the film will last for years, and, if care is taken not to uncover when the mirror is colder than the air, condensation on the film will be avoided. If the mirror does mist up, under no circumstances touch it, but dry it off with the hair dryer. A film is quite hard, tough, and adherent, when dry, but very fragile when damp. So don't let it get damp.

There are one or two 'don'ts' to remember when using silver/ammonia solutions. While inert at these concentrations and temperatures, it is unwise to let them dry in the glass, and to allow cotton wool swabs used with them to dry, as they could conceivably become explosive. To swill out glasses and dispose of swabs as the last process in silvering is a safe rule, and don't go off for a picnic after mixing solutions and before using them. Also, the solutions stain, so it is as well not to get too much on the fingers. It only takes an hour to silver a mirror, but the stains last till next week.

The 1971 Mars Probes

HOWARD MILES

'Photographs of the Martian surface obtained from the American *Mariner 9* show a fantastic range of brand new phenomena that no-one suspected existed on the planet.' These words were used by the Director of Planetary Science at Cornell University, Dr Carl Sagan, when commenting on the first photographs of the planet's surface to be transmitted after the violent dust storms had died down. From the time that the first telescopes were turned on the planet, Mars has been the centre of one sensation after another. Although quite a difficult object in small instruments, due mainly to the fact that Mars is a very small planet, most observers can readily detect the brilliant white polar caps, the dark areas which appear to change with the Martian season, and the orange-red areas, popularly referred to as the deserts. Larger instruments give finer details within these regions, including the linear markings thought at one time by some observers to be canals. Different observers have expressed widely different explanations for these markings and so it was with great interest that man waited for the first detailed photographs of the surface taken from a spacecraft.

The first of these were transmitted back to Earth in 1965 by the American probe *Mariner 4*. Although only covering about 1 per cent of the surface, it showed that it was covered with craters, with virtually no difference between the dark and desert areas. No linear markings were seen. *Mariner 6* and *Mariner 7*, sent to Mars in 1969, provided information on about 10 per cent of the surface and showed that, apart from a few well-defined areas, the surface was heavily cratered, in agreement with the earlier probe. Much information was sent back on the nature of the polar caps. Many questions remained unanswered and many new questions were asked. Consequently everyone eagerly awaited the results of two probes planned to be fired in the direction of Mars in the spring of 1971. Unlike the earlier probes, which just flew past the planet, these were designed to go into orbit round Mars and send back information for about three months. Unfortunately, the first of these failed during the launch and crashed, leaving the other, designated *Mariner 9*, to carry out a modified programme to provide as much information as possible.

Because of limitations imposed by rocket design and fuel requirements, it is only possible to send probes to Mars at intervals of about twenty-five months. The Soviet Union also took advantage of the 1971 launch window, and despatched two probes on 19 and 28 May respectively. No details of the purposes of these two spacecraft, designated *Mars 2* and *Mars 3*, were released in the early stages except to say that they were intended to explore the planet Mars and neighbouring space. Earlier Soviet probes, *Mars 1* and *Zond 2*, launched in 1962 and 1964 respectively, can be considered as failures as far as sending back details of the planet is concerned.

All three probes travelled along relatively similar paths and all were successfully placed into orbits round the planet, *Mariner 9* on 13 November 1971 and *Mars 2* and *Mars 3* on 27 November and 2 December respectively. The initial orbital parameters of these are given in the table:

	Mariner 9	*Mars 2*	*Mars 3*
Orbital inclination to Mars equator	64·3°	49°	not available
Period of revolution	12 hr 34 min	18 hr	11 days
Maximum distance from the planet	17,820 km	25,000 km	189,000 km
Minimum distance from the planet	1,390 km	1,380 km	1,500 km

Just before entering into Martian orbit, *Mars 2* ejected a capsule which subsequently placed on the surface of Mars a pennant showing the U.S.S.R. coat of arms. In the case of *Mars 3* the ejected capsule made a soft landing and transmitted information from the surface for 20 seconds before going dead. The soft landing was made by parachute at latitude 45°S, longitude 158°W, a position lying between the regions known as Electris and Phæthontis. When the probe reached a height of 25 metres above the surface, a retro-rocket was fired and also the parachute system was discarded so as to avoid any possibility of it falling over the instrument package. Within 1½ minutes of landing the package was activated and at 13.50.35 UT it transmitted a TV picture of the Martian surface to the main orbiting spacecraft for storage and subsequent transmission to Earth. At present the reason for the sudden failure is unknown. Various theories have been put forward, such as the very high winds and the dust storm. Some have suggested that it may have sunk into soft surface material, and others that the parachute may have been responsible.

The American *Mariner 9* was a more sophisticated version of the earlier probes. At launch it weighed about 1000 kg; but after Mars insertion, most of the fuel on board had been used and this reduced the weight to 544 kg. The orbit chosen was such that the probe would not crash on to the surface of the planet for at least 17 years to avoid contamination before studies have been carried out by future spacecraft. The investigation of Martian conditions involved six experiments, although two of these did not require special instruments. Photography of the Martian surface (see photographs, pages 138-140) and of its two natural satellites was achieved with two camera systems, one having a narrow angle and the other a wide angle. The latter was capable of giving a resolution of about 1 km, but the telephoto system reduced this to about 100 metres. It was planned that during the 90-day basic period of orbiting the planet, the cameras would return about 9000 photographs, but, unfortunately, because of the severe dust storms that existed

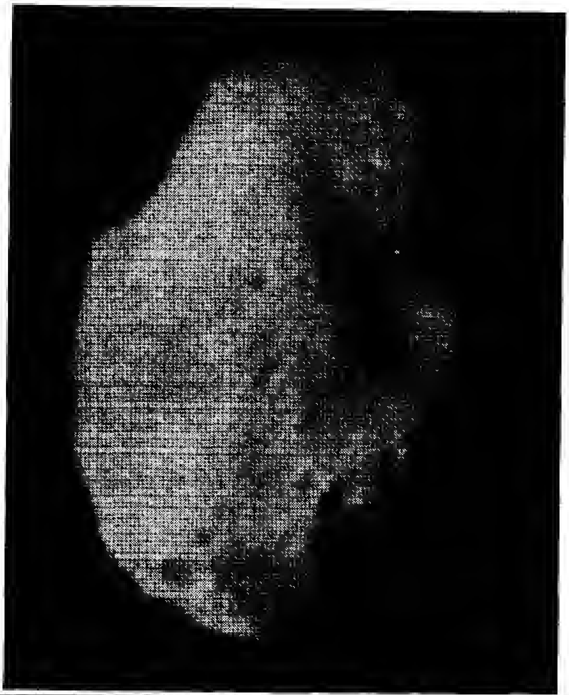


Fig. 1

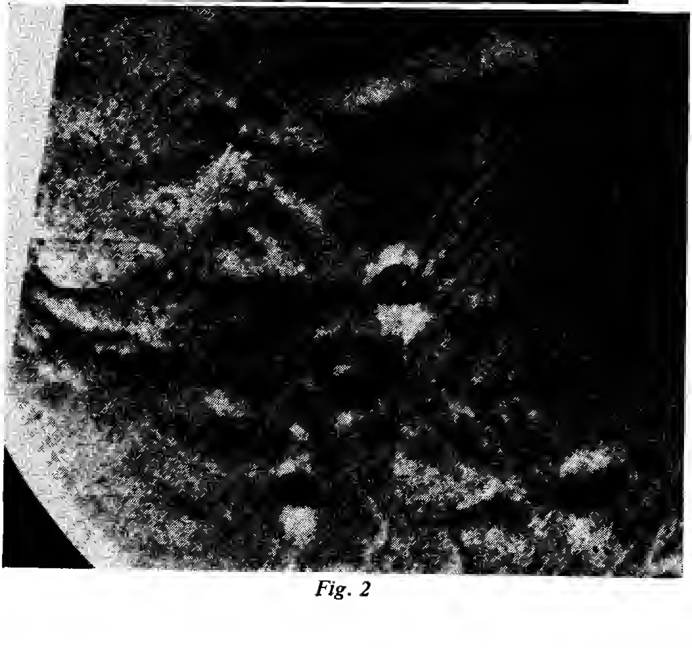


Fig. 2

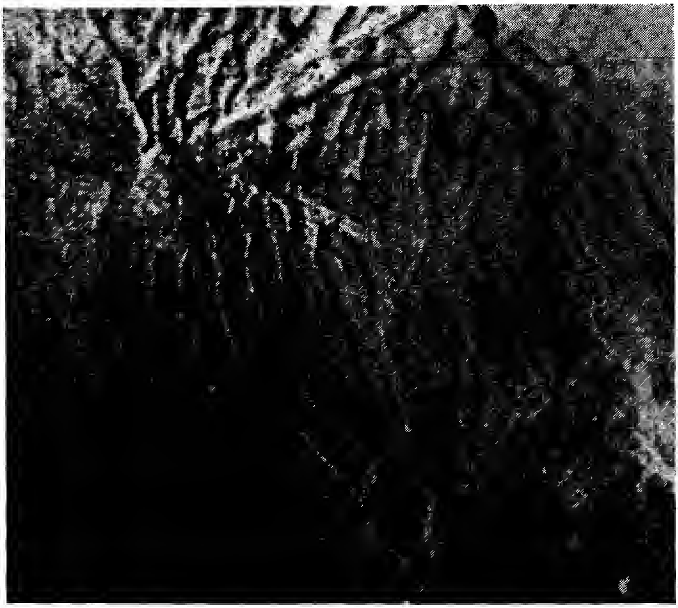


Fig. 3

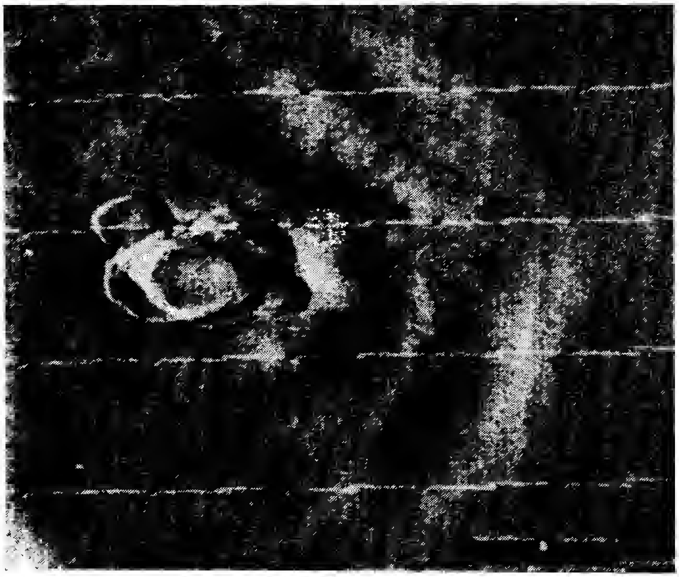


Fig. 4

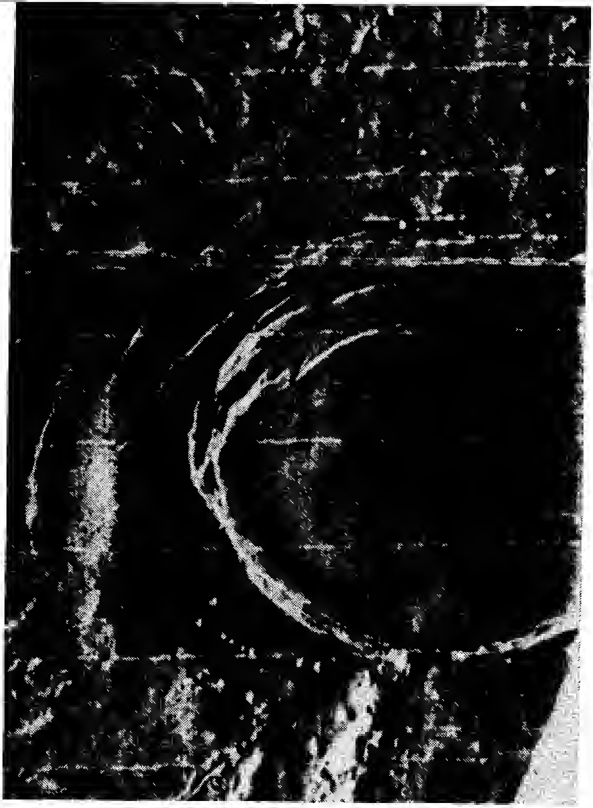


Fig. 5

Figure 1. This is one of the first photographs to be obtained of Phobos, the larger of Mars' two natural satellites. It is approximately 16 km by 22 km. The existence of craters on Phobos and its irregular shape make it with the other satellite Deimos, an extremely attractive target for research.
Figure 2. A mosaic of pictures taken by *Mariner 9* just prior to entering into orbit around Mars. The upper of the three prominent features in the centre has been identified as Arsia Silva, just south of the equator. It is about 200 km in diameter. The streaks pointing northwards are over 1000 km long.
Figure 3. A photograph of Phœnicis Lacus, taken after the dust storm had died down. Even so, all areas lying lower than 5·6 km above the surface are still hidden by dust. This photograph was taken on 17 December.
Figure 4. Mariner view of a complex crater near Ascraecus Lacus. It measures about 40 km across. The circular arcs surrounding the feature are thought to be atmospheric.
Figure 5. A 110 km diameter crater in the region of Nodus Gordii. The crater is on high ground and is protruding above the dust storm. This photograph was taken on 28 November. The multiple concentric fractures and the large number of small craters suggest that the feature may be a volcanic collapse crater.

Acknowledgement: All NASA photographs.

during the first half of the period, the complete mapping programme was not achieved. During the approach to the planet, the photographic sequence was designed to provide coverage of a complete revolution of the planet as it rotated in front of the spacecraft. In addition, the programme included the recording of photographs of Phobos and Deimos. With the exception of a single low-resolution picture of Phobos taken in 1969, the Martian moons had not been seen other than as points of light. The photographs of Phobos (Figure 1, page 138) shows it to have quite an irregular shape, and to be covered in craters of all sizes.

Detection of life on Mars is beyond the resolution capabilities of the cameras. The photographs, however, can be used in conjunction with details from the other experiments to provide information on whether the conditions existing on the planet permit life as we know it.

The south polar region was singled out for detailed study by the cameras. Of particular interest were the ridge-like structures seen on the earlier probe. At the end of 1971, the southern hemisphere was experiencing a Martian summer and hence much of the polar snow seen in the 1969 *Mariner* pictures would have disappeared, revealing – it was hoped – the underlying surface features. At the time of writing these notes, no information has been received on this interesting aspect. It was also hoped to use the TV system for drawing up more accurate maps of the surface features and determining the shape of the planet. There exists a persistent discrepancy between the optical observations from Earth and the data derived from the orbits of the two natural satellites and the trajectories of the previous spacecraft. The existing maps of Mars give positions of surface features to an accuracy of about 1° or 50 kilometres. Using the wide-angle system, it is hoped to reduce this to about 1·6 km.

The camera systems were mounted on a platform which could be rotated about two axes, so permitting the direction of the platform to be updated on each orbit. Included on the platform were the U/V and the two infra-red experiments. These were designed to study the composition and physical properties of the atmosphere and surface of the planet. The U/V spectroscope provided information amongst other things on molecular oxygen as well as ozone. Generally the U/V experiments gave information on the region from the surface to about 1000 km, whilst the I/R experiments concentrated on heights up to about 100 km. At the same time as probing the secrets of the atmosphere, the U/V spectrometer also provided details of the elevation profile of the surface. Over high ground, the amount of atmosphere is less than that in the lower regions and hence the intensity of the radiation could be linked directly with the height of the surface.

An experiment not requiring special equipment provided much information on the atmosphere and surface. Each time the probe passed behind the planet, the S-band radio signal received back on Earth was gradually modified and finally cut off. The rate of fall provided measurements of the density and pressure of the atmosphere. Previous occultation experiments on the earlier probes had showed that the surface pressure is only about 1 per cent of that at the Earth's surface. The other experiment which did not require special equipment, the celestial mechanics experiment, involved the radio tracking of the spacecraft throughout the whole of its flight. This will have provided a more accurate description of the Martian gravitational field than has been possible from a study of the orbits of the two moons. The determination of a more precise value of the distance between Earth and Mars will permit the astronomical unit to be determined more accurately. An interesting extension of this experiment will arise when Mars has moved in its orbit to a point in line with the Sun as seen from Earth. At this time radio signals to and from the spacecraft will have to pass very close to the Sun, a condition which is suitable for testing Einstein's theory. If the theory is correct, the gravitational field of the Sun will bend the radio waves by a small amount, causing the signals to travel over a slightly longer path than they would have done if the path had been a straight line. This will result in the signal being delayed by about 0·0002 seconds. The actual delay recorded is capable of being measured to an accuracy of one millionth of a second, and so the situation affords a suitable time for checking the theory.

Within one week of arriving in the vicinity of the planet, *Mariner 9* provided very interesting information. Water vapour, not detected by any of the earlier probes, but had been from Earth-based observations, was identified in some abundance over the south polar cap. The orbital behaviour of the probe as it circled the planet provided information on its gravitational field. Dr Lorell, Head of the Celestial Mechanics Group, reported that Mars was 'on a large scale rough gravitationally and on a small scale also rough'. He spoke of Mars as triaxial, one axis lying north-south through the poles, one east-west through the equator and a third axis along a diagonal line north and south of the equator. In addition there were small localized areas which could be likened to the lunar mascons. These irregularities produced a very marked effect on the *Mariner* orbit, the period of which fell by 40 seconds during the first eight revolutions.

After sending capsules to the surface, the Russian *Mars 2* and *Mars 3* went into contrasting orbits, thus giving the opportunity of examining conditions over a wide region round the planet. Both probes carried cameras for recording surface details. Unlike the American probe, which used a TV camera directly, the Soviet probes took photographs using film which was then processed on board the spacecraft using standard chemical processes. The negatives were then scanned by a TV scanning system and this signal transmitted back to Earth. A similar system was used in the American *Lunar Orbiter* probes which resulted in the remarkable pictures of the lunar surface. The Russians have stated that an important feature of the system was that it provided very high quality photographs. Like the American counterparts, the camera system consisted of two instruments, one using a wide-angled lens and the other a telephoto system having a field of view of about 4°. The photographs were taken through a series of coloured filters, thus providing much extra information on surface details.

Like *Mariner 9*, the Russian probes carried out experiments using infra-red and ultra-violet radiation. In the infra-red region, three different aspects were investigated. The first measured radiation in the range 8-40 microns, and was able to show areas having different temperatures. Another instrument provided information on the varying height of the surface. Since the Martian atmosphere is mostly carbon dioxide, the recording of various intensities can be linked directly with the thickness of the carbon-dioxide layer, and hence with the height profile, just as the American carried out using their U/V spectrometer. The third experiment was designed to investigate the concentration of dust particles at different levels in the atmosphere, the colour of the Martian rocks and to study twilight atmospheric phenomena. A radio telescope operating in the 3 cm waveband recorded radiation in this region of the spectrum from the planet's surface. The information made it possible to determine the temperature at a depth of about 50 cm below the surface as well as the composition of the soil. The U/V experiment was designed to investigate the composition of the atmosphere, with special reference to hydrogen, oxygen, and argon. A multi-channel U/V photometer was programmed to read the intensity of the airglow in the upper layers of the atmosphere.

At the time of writing (January 1972) only isolated pieces of information have been released, and unfortunately this prevents the giving of a coherent picture of conditions on the planet. It is only possible to quote some isolated facts. These are, in themselves, very interesting, and are sufficient to make astronomers revise drastically their previously held views. Circumstances have been complicated by the fact that for most of the latter half of 1971 the Martian surface experienced one of the severest dust storms ever recorded. Evidence sent back by the probes indicated that by the end of the year the storm had begun to die down but until then the storm had prevented the experimenters from receiving detailed information of the planet's surface. Their disappointment has, however, been overshadowed by the fact that for the first time one has been able to obtain a detailed account of a storm, information which may turn out to be of greater importance than the receipt of photographs of the quiet surface.

Information from the Soviet radio-frequency experiment have given some clues to the nature of the Martian rocks. Earlier Earth-bound studies indicated that the reddish tint to the rocks was likely to be due to the presence of iron-oxide minerals such as limonite and haematite. Information received from the probes has shown that it is unlikely to be the case. It is now thought that the surface consists of silicate particles possibly resembling desert sand on Earth, these particles being covered with a thin layer of iron oxide. The average density of the rocks to a depth of 10 metres has been found to be 1·3 grams per cubic centimetre. The equipment could detect very little difference between the dark and light areas, and could provide no information as to the reason for the two types of colouring. The temperature at depths of about 50 cm remains fairly constant at below −50-70°C. At latitudes of 15-25°, this layer consists of silicate soil bonded together with water-ice. At higher latitudes, however, the permafrost layer is much nearer the surface. The infra-red radiometer has so far not found an area where the surface temperature is greater than −15°C. On the night side, areas were located where the temperature appeared to be 20-25° higher than the surrounding regions, which in some places dropped to as low as −90°C.

The U/V experiments have indicated the presence of atomic hydrogen and oxygen in the upper atmosphere, with hydrogen being detected at heights in excess of 3,500 km. Atomic oxygen has been detected up to about 700 km. Very little water vapour has been recorded. In the areas investigated, this does not exceed 5 microns of precipitated water. This contrasts with the *Mariner* findings over the south polar regions.

The photographs sent back by *Mariner 9* showed craters situated on high ground and protruding above the dust storms. Other photographs showed evidence of infilling of craters by dust. A picture received after the storm had subsided to a marked degree revealed stretches of deeply pitted Martian landscape, with a system of parallel rilles extending for more than 1,700 km. Others showed extensive 'leopard spot' patterns of dark patches on a lighter background and areas with a high density of cratering. Others showed evidence of considerable erosion and volcanic activity. In fact, scientists at the Jet Propulsion Laboratory, California, believe that Mars is not a dead world like the Moon but is still evolving. The 'leopard spots' appear to occur in all sizes up to diameters of 160 km, and are associated with craters. Comparison of photographs of areas covered by *Mariner 9* and earlier probes have shown changes in the appearance of some surface features, a fact which strengthens the belief that the surface is still active.

It is obvious that much more information is going to be obtained from all the three probes. It is also obvious that there are many more sensational surprises in store. Analysis of the information takes time and it will be many months before the full story is known. The agreement reached between the Americans and the Russians in 1971 for full and rapid exchange of information gleaned from their respective probes will speed up the time when we will have a reasonably accurate picture of a planet which has shown to be, like Venus but in an entirely different way, quite a hostile place!

The Constitution of Jupiter

GILBERT E. SATTERTHWAITE

Many observers regard Jupiter as the most rewarding of the planets to study, for no other can equal it in the wealth of detail that can be discerned with telescopes of even moderate aperture. Furthermore, the appearance of the visible surface of the planet is constantly changing, which further increases the popularity of Jupiter with amateur observers. One great advantage which the dedicated amateur enjoys over the professional astronomer is the fact that he is able to devote as much of his observing time as he likes to the study of a single object that interests him. The constantly changing features of the surface of Jupiter have been monitored for more than a century by a great many devoted amateurs in several countries, whose efforts have provided a storehouse of information about the planet that is of inestimable value to anyone wishing to study the planet in any of its many aspects.

As constant change is the keynote of Jovian surface activity, even the advent of photography did not diminish the value of visual observations of the planet. Photographs record the surface features only at a given moment in time, and even though photographic monitoring of the planetary surfaces is now carried out throughout the world with several telescopes specially constructed for the purpose, and some magnificent photographs have been obtained, exposures are seldom made frequently enough to show short-term variations. Thus, there is clearly a continuing future for the visual observer, although it is necessary for him to keep his techniques and programmes constantly under review and to realize that his work will continue to be useful only if it is planned to supplement that of the professional observatories.

In this article we are concerned with the observed features only in so far as they are an indication of activity in the outer layers of the planet. Most of our ideas about the deep interior are based upon reasoned speculation, but theoretical studies of this kind must constantly be compared with observation in order to ensure that they are consistent with whatever factual data we have at the time.

Dimensions and Physical Data of the Planet

The largest planet in the Solar System, Jupiter has an equatorial diameter of 142,800 km. Due to its rapid axial rotation – one revolution occupying less than ten hours – it is an oblate spheroid; the polar compression is such (about 1:15) that the polar diameter is only 133,500 km.

Jupiter is the fifth planet in order of distance from the Sun, the mean distance being 778,340,000 km. Although its volume is 1318·7 times that of Earth, its mass is found by dynamical analysis to be only 317·9 times the Earth's mass. This indicates that the mean density of Jupiter is rather less than one-quarter that of the Earth – 1·33 g/cm^3 – a fact which imposes a number of restraints on the possible nature of the planet's interior.

Other physical parameters which must affect the activity in the surface layers of the planet are the temperature at the surface – a mean value of about 150°K – and the planet's own gravity. The force of gravity at the surface of Jupiter is 2·64 times that at the surface of the Earth. The resulting velocity of escape for gases is 60·2 km/sec.

The surface of the planet is clearly of a gaseous nature, revealing a number of dusky cloud *belts* interspersed with lighter *zones*. From observations of condensations in the belts and other discrete features the rate of rotation of the planet has been determined in each latitude. Although there are slight variations, most of the features observed over the greater part of the globe have rotation periods close to 9h 55m 40s; there is a 'great equatorial current', however, which has a much faster rotation period (9h 50m 30s): it extends for about 10° north and south of the equator. The rotation of the planet is very fast for so large a body – equivalent to a linear velocity at a point on the planet's equator twenty-eight times that of a corresponding point on Earth. Clearly this must have a limiting effect upon the kinds of physical activity possible in the dense, cloudy layers that form the visible 'surface' of the planet.

The Internal Structure of the Planet

(i) *Early theories*

It has long been recognized that the structure of the four major planets must, in view of their remarkably low mean densities, be quite different from that of the smaller, predominantly rocky, terrestrial planets. The four terrestrial planets (and probably Pluto) have mean densities of 4 to 5 times that of water, whereas those of the major planets range from $1\frac{3}{4}$ to $\frac{3}{4}$ times the density of water. Saturn is especially notable, being considerably *less* dense than water (0·71 g/cm^3): this has been likened to the density of loosely packed, freshly fallen snow. Jupiter has a density almost double this value, but nevertheless its density is so low that it cannot possibly be at all like the terrestrial planets, which comprise a predominantly solid globe surrounded by a relatively shallow gaseous atmosphere.

The earliest studies of the constitution of Jupiter and the other major planets which are relevant today are those carried out by Sir Harold Jeffreys at Cambridge half a century ago. Jeffreys suggested that each major planet consisted of a relatively small rocky core, surrounded by a deep layer of ice, the whole in turn being surrounded by a very deep gaseous atmosphere. Jeffreys suggested that the ice and gas layers would be of considerable depth, thus accounting for a large part of the planet's total volume. In this way the very low mean density could be accounted for.

This theory was developed by Rupert Wildt (now at Princeton, U.S.A.) at Göttingen in the 1930s. Wildt calculated theoretical models for each of the major planets, proposing for Jupiter a solid, rocky core about 60,000 km in diameter, with an ice mantle about 27,000 km deep and a gaseous atmosphere about 13,000 km deep.

The confirmation that absorption bands in the planet's spectrum were due to the presence in its outer layers of considerable quantities of ammonia and methane (*see below*) accorded well with contemporary theories of the evolution of the major planets – especially those of H. N. Russell. Russell suggested that each giant planet was initially a large hot sphere of hydrogen and helium, mixed with a little nitrogen, carbon dioxide and water vapour. As the planet cooled the carbon dioxide and hydrogen would react, producing methane, and at a later stage hydrogen and nitrogen would combine to form ammonia. Eventually no carbon dioxide or free nitrogen would remain in the 'atmosphere', which would then consist mainly of hydrogen, helium, methane, ammonia, and water vapour.

Wildt calculated that roughly equal amounts of ammonia and methane would be present in the planet, but that methane would be more abundant at the observable surface as the ammonia would be condensed out at a lower level. This was also confirmed by the spectra. Wildt also calculated that about one-tenth of the mass of Jupiter would consist of hydrogen: this was a surprisingly low figure, for the major planets were considered to have been formed from material of similar composition to the Sun – which contains more than 90 per cent hydrogen.

Although Wildt's proposed model was generally accepted for many years, this disparity was difficult to explain and it was not really surprising that a totally different theory of the planet's internal constitution was eventually propounded.

(ii) *Theories of gaseous constitution*

The new approach was the work of W. H. Ramsey of the University of Manchester. In the early 1950s Ramsey developed the theory that the major planets had no solid core but each comprised a homogeneous mixture of gases which varied only in density, due to the gravitational compression at increasing depths below the surface. Ramsey suggested that the main constituents of the gaseous mixture would be hydrogen and helium, and that Jupiter consisted of 76–84 per cent hydrogen – a figure much more in accord with the theories of planetary evolution. It was known that at very high pressures hydrogen could undergo a phase transition into the form of an electrically conducting, alkali metal. Ramsey showed that the pressure at the centre of Jupiter was more than forty times the pressure required to bring about this phase-change, and suggested that all the hydrogen in Jupiter beneath a certain critical depth would be in the metallic form. Ramsey also showed that his results would still apply if, in fact, Jupiter had a small solid core – a suggestion that is favoured by a number of theoretical astronomers at the present time.

Recently, most theories have been broadly in agreement, that the planet largely consists of hydrogen, metallic at depths greater than about 15,000 km and fluid above. Some helium and very small quantities of other substances may be mixed with the hydrogen, and some authorities believe that there may be a solid core of perhaps 10–15,000 km radius. It is the outermost, fluid layers of the planet, usually referred to as its 'atmosphere', which are of particular interest to the observer, for it is there that most of the observable surface phenomena must originate.

The Observed Surface Features

The familiar appearance of the planet's surface, with its dusky cloud belts, interspersed with lighter zones and parallel to the planet's equator, is subject to continuous, though relatively small-scale changes. These have been constantly monitored by visual observers, mostly amateurs, for more than a century and most of our knowledge of the activity in the surface layers is based upon their work.

Although more or less constant in latitude, the various belts do in fact show slight variations in both latitude and in width. They also vary in intensity, in colour, and in structure. Continued observation of these changes is vital to our further understanding of the complex 'meteorology' of this fascinating planet.

Within the scope of this article only a few of the more interesting kinds of surface activity can be briefly outlined.

It is assumed here that the reader is familiar with the nomenclature of the belts and zones on Jupiter, and with other terms such as 'preceding', 'following' and 'rotation period' used by observers. Those who are not familiar with this nomenclature will find it fully detailed in the literature.*

(i) *Structure of the belts*

Any particular belt may appear quite different in intensity and width from one apparition to another, and may even disappear entirely for a time. In addition to these changes on a time-scale of months a belt may appear quite uniform and smooth in outline, or may have a quite complex 'structure' of spots and streaks of varying intensity and colour, which may be seen to alter from day to day or even, occasionally, from hour to hour. Most active in this respect are the Equatorial Belts, which sometimes appear single and broad and sometimes divided into two narrower components. They usually show variations in intensity, in the form of 'condensations' or streaks, and are also subject to 'outbreaks' or major 'disturbances' from time to time. These usually take the form of a rapid increase in the number of light and dark spots visible within the belt, which often show rapid motions. A typical pattern is for a sequence of such spots to be formed at a specific location within the belt, and to move rapidly along the belt away from their point of appearance. Frequently the light spots move in one direction and the dark ones in the other. Activity of this kind can, even after a few days, reduce the belt's structure to chaotic complexity. Due to the rapid rotation of the planet, and the consequently short and sporadic intervals during which the activity can be watched, our knowledge of the development of outbreaks of this kind is

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*e.g., in the author's *Encyclopedia of Astronomy* (Hamlyn, 1970) or Patrick Moore's *The Amateur Astronomer* (7th edition, Lutterworth Press, 1971).

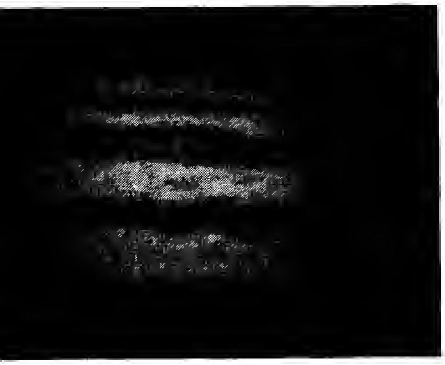

Fig. 1a

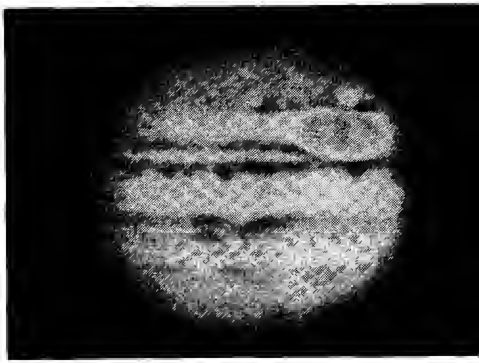

Fig. 1b

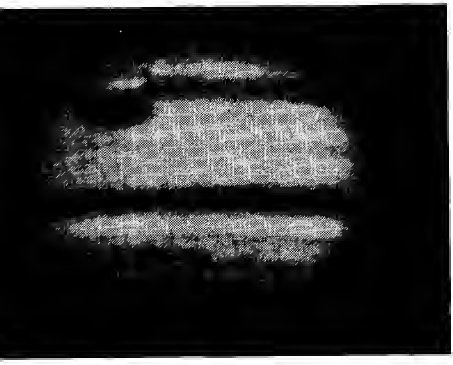

Fig. 1c

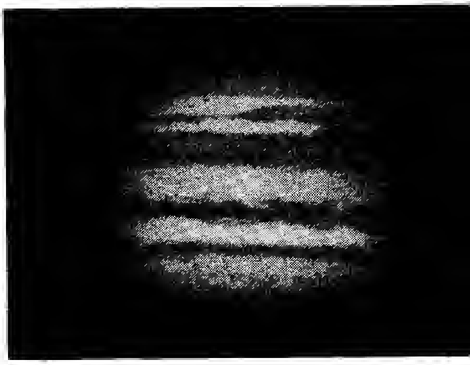

Fig. 1d

(Note that each picture shows the planet as seen in the northern hemisphere with an astronomical telescope – i.e., with the South Pole uppermost.)

(*a*) Photographed by E. C. Slipher with the 60 cm refractor at the Lowell Observatory, Flagstaff, Arizona, October 19 1915. [*Courtesy, Lowell Observatory*].

(*b*) Drawn by E. M. Antoniadi with the 82 cm refractor at the Meudon Observatory, Paris, May 22 1911.

(*c*) Photographed in blue light with the 200-inch (508 cm) reflector at Mount Palomar Observatory, California, October 24 1952. [*Courtesy, Mount Wilson and Palomar Observatories.*]

(*d*) Photographed by E. C. Slipher with the 60 cm refractor, Lowell Observatory, December 19 1917. [*Courtesy, Lowell Observatory.*]

still far from complete and many more observations of them are needed.

There is some evidence that major outbreaks in the Equatorial Belts may recur periodically, at intervals of five to ten years. The most recent outbreak, in the North Equatorial Belt, occurred in 1971.

Plate 1(*a*) shows the North Equatorial Belt in a very disturbed state: note the curved filaments from the southern edge of the belt across the Equatorial Zone – these are a feature frequently observed on the planet and may be an important indication of atmospheric motions in the equatorial region. Plate 1(*d*) also shows the North Equatorial Belt disturbed.

(ii) *The Great Red Spot region*

The best-known feature of the planet, the Great Red Spot, is also one of the most puzzling. It is a vast oval formation, approximately 25,000 × 10,000 km, with its major axis parallel to the belt–zone system. It is situated in the South Tropical Zone, i.e. in Jovian latitude about 22° South. It is the most permanent single feature on the planet: the earliest recorded observation of it was made by Robert Hooke in 1664. Its appearance and rotation period were observed by G. D. Cassini between 1664 and 1672, during which time its rotation period shortened by 5 seconds. Cassini was thus the discoverer of the Red Spot's erratic motion in longitude – an aspect of its behaviour that has proved quite remarkable and difficult to interpret in the succeeding years.

Hooke's spot was observed sporadically until 1713, when it apparently disappeared for more than a century; it was not seen again until 1831, when it was drawn by Heinrich Schwabe – the German discoverer of the sunspot cycle. Although the Spot itself has disappeared from time to time, the unmistakable appearance of the area surrounding it has never been totally absent since that time. The Spot is not centred in the South Tropical Zone, its centre lying well to the south of the centre-line of the Zone so that the Spot intrudes into the South Equatorial Belt.

There appears to be some kind of incompatibility, however, between the material of the Spot and that of the Belt, for they are never seen to merge. There is usually a sharp distinction of colour and intensity between them and, almost always, the Spot is quite separated from the material of the Belt by a clear white space (see Plate 1(*b*)) which forms a huge bight in the Belt. This feature, known as the Red Spot Hollow, remains visible even on those occasions when the Spot itself disappears.

The Red Spot is in fact very variable in colour; a pale pink when rediscovered in 1831, it gradually deepened to a deep brick-red, which it remained until 1882. Since that time it has faded to virtual invisibility on a number of occasions, and has revived again. Though often appearing grey or just faintly pink, it has sometimes attained a fairly strong red colour again, notably in 1936 and 1965-72. It has frequently appeared to have a dark perimeter and paler interior; some of the best high-resolution photographs have recorded a more complex interior structure, however, with several lighter patches, or occasionally a darker, elongated central patch. (See Plate 1(*c*), a photograph taken in blue light, so that the Red Spot shows up very dark.)

The Red Spot has always displayed erratic movements in longitude, drifting back and forth along the Zone relative to other markings. If all the movement had been in the same direction the Spot would have completed more than three circuits of the globe in a century. It was pointed out by B. M. Peek in 1939 that each darkening of the Spot coincided with a deceleration in its motion; recent work by G. Solberg has revealed a regular oscillation in longitude of the order of 1°, with a period of 90 days.

(iii) *Other activity in the South Tropical Zone*

The South Tropical Zone seems for some reason to be particularly prone to peculiar kinds of activity. One of the most notable phenomena observed in this Zone is the South Tropical Disturbance, first recorded by P. B. Molesworth in 1901 as a grey ligament across the Zone, connecting the South Equatorial and Temperate Belts. The marking rapidly extended in longitude, forming a darker portion of the otherwise light-coloured Zone. The manner of its growth suggested an injection of dark material from below, being spread along the Zone by the rotational flow of the surface currents. Bright patches soon appeared at each end of the Disturbance, giving the dark feature the concave ends which were to characterize it thereafter. It attained considerable length, stretching more than half way round the planet. In time its central portion faded, leaving the ends dark and well defined. The rotation period of the Disturbance was slightly shorter than that of the Red Spot, causing it to overtake the Red Spot every few years (the exact frequency was variable, due to the changing rotation period of the Red Spot).

The behaviour of the South Tropical Disturbance on overtaking the region of the Red Spot was quite remarkable: instead of flowing straight across the region, the dark material of the Disturbance, on reaching the following end of the Red Spot Hollow, broke up and flowed around the perimeter of the Hollow to the north and south. Having thus passed the Red Spot without actual contact, the dark material coalesced, once it had passed the preceding end of the Hollow, to reform the Disturbance once more. This passage was accomplished in the course of a few days only, compared with the six weeks or so that would have been required at the rate of motion of the Disturbance before and after the passage. This pattern of behaviour was faithfully repeated at succeeding encounters between the Disturbance and the Red Spot region.

The South Tropical Disturbance persisted until 1940, although varying considerably in length, intensity and structure during that time. In more recent years it has reappeared occasionally, though never so prominent or extended; neither has it persisted for more than a few months.

The South Tropical Disturbance is clearly visible in Plate 1(*d*), joining the broad South Equatorial Belt to the thickened portion of the South Temperate Belt above. Note the concave preceding end of the Disturbance. Although it has been recorded by visual observers many times, this excellent 1917 photograph is one of very few which show the Disturbance.

Another fascinating phenomenon in the South Tropical Zone, which probably is also an important clue to the motions of the surface layers of the Jovian 'atmosphere', first occurred during the 1919-20 apparition. After a previous fading the South Tropical Disturbance had just returned in prominent and turbulent state. Two small dark spots appeared in the undisturbed part of the Zone, about 60° apart in longitude and quite close to the northern edge of the Zone. They shared a remarkable motion in longitude, about 4° per day towards the *following* limb of the planet – i.e. *against* the normal flow of the surface currents. Both spots disappeared shortly before reaching the preceding end of the South Tropical Disturbance, but were succeeded by an identical pair of spots, also almost 60° apart and sharing a motion of 4° per day, but this time they were close to the southern edge of the Zone and the motion was towards the *preceding* limb. It was as if the spots had been turned around the concave end of the Disturbance and dispatched back along the undisturbed part of the Zone. Both spots finally faded away before reaching the other end of the Disturbance.

This remarkable phenomenon was observed again during the apparitions of 1928, 1931, 1932–3, and 1934. On these occasions a whole series of spots were seen to behave in this remarkable manner, though often they were not separate spots but dark condensations in, or 'humps' on the edges of, the belts bordering the Zone. They were always stopped by the preceding end of the Disturbance and many were seen to have been 'turned back' by it; unfortunately there were no positively confirmed observations of spots being similarly diverted by the other end of the Disturbance, although there are grounds for suspecting that this happened on some occasions, but the feature nevertheless became known as the Circulating Current.

The abnormal drifts of the Red Spot and its Hollow, the South Tropical Disturbance, and the associated Circulating Current, focus attention on the South Tropical Zone as one of the most puzzling and perhaps significant regions of the planet.

(iv) *The South Temperate white spots*

The South Temperate Belt is one of the most permanent, and often most prominent, belts on the planet. As one of the belts bordering the very active South Tropical Zone it has naturally been closely watched by observers throughout the present century. In the 1939–40 apparition – significantly the time of disappearance of the long-lived South Tropical Disturbance in its original manifestation – the South Temperate Belt itself became the scene of some very interesting behaviour. A thin grey streak sometimes seen in the South Temperate Zone (adjoining the Belt to the south) strengthened in places to give the appearance of a double South Temperate Belt; the light area between the two components did not stretch all round the planet for long, however. By the following apparition the component belts were linked by dusky material in three places, dividing the light strip into three parts. The three dark markings steadily expanded in longitude for the next decade; they were identified by the letters AB, CD, and EF. By 1943 the dark patches exceeded the lighter interstitial spaces in length; by 1950 the latter had been reduced to three white oval patches less than 30° in length. They exist in this form today, and are still known, by the letters originally allocated to their ends, as FA, BC, and DE. They are centred roughly on the southern edge of the South Temperate Belt, extending into the South Tropical Zone. They share a rotation period about half a minute less than that of the Red Spot, so that from time to time they overtake the Spot. These encounters are suspected of causing unusual activity, which may be connected with the erratic bursts of 'noise' observed with radio telescopes.

One of the three white ovals can be seen in Plate 1(*c*), photographed whilst in conjunction with the Red Spot. In Antoniadi's 1911 drawing, Plate 1(*b*), two earlier, smaller white spots on the South Temperate Belt are visible.

(v) *Activity in the Equatorial Zone*

This region is often the scene of interesting activity, though the features observed are usually rather faint. Activity in this Zone is the more interesting since it forms the greater part of the great equatorial current, with its very short rotation period. A faint, narrow, equatorial belt or 'filament' is often seen, central in the Zone. Condensations or humps on the edges of the Equatorial Belts are common (a number can be seen on the edge of the South Equatorial Belt in Plate 1(*b*)); frequently these take the form of arcuate filaments reaching out across the Zone (as in Plate 1(*a*)), enclosing or partly enclosing oval areas of the Zone. Sometimes these ovals appear brighter than the remainder of the zone.

Spectroscopic Observations and Chemical Composition

The spectra of the major planets were first observed by both Huggins and Secchi between 1863 and 1865; they were thus among the first celestial objects to be so studied. The interpretation of their spectra proved difficult, however, and little progress was made towards a real understanding of their chemical composition for half a century.

Huggins and Secchi both discovered that the spectra of the four giant planets contained a number of strong, broad absorption bands. Their spectra were further examined by Keeler in 1889, and they were first recorded photographically by V. M. Slipher at the Lowell Observatory in 1905. Slipher found that there were further strong absorption bands in the infra-red spectra.

The substances giving rise to these strong absorptions remained unknown until Wildt, in 1932, deduced from a purely theoretical exercise that they were most probably due to large quantities of ammonia (NH_3) and methane (CH_4) in the outermost layers of the planets' 'atmospheres'. This difficult identification, reflecting great credit on Wildt, was later proved by comparing high-definition infra-red spectra of Jupiter – obtained by Dunham with the 100-inch reflector at the Mount Wilson

Observatory – with laboratory spectra produced at Lowell by Adel and Slipher.

Although methane, and to a lesser extent ammonia, reveal their presence by such strong absorption bands, they are by no means the major constituents of even the outer layers of the planet. According to modern estimates methane and ammonia together probably account for no more than one per cent of Jupiter's 'atmosphere'; the less-easily detected gases helium and neon probably account for 36 and 3 per cent respectively, the remaining 60 per cent being hydrogen. Unfortunately few substances show up well in spectra produced at the low temperatures which obtain on Jupiter. The hydrogen content of the outer layers is significantly less than the 80 per cent or so predicted for the planet as a whole. Probably the best estimate of the constitution of Jupiter's 'upper atmosphere' is a 2:1 hydrogen – helium mixture, with a little neon and methane, and with small quantities of a number of other substances suspended in it. These probably include a layer of hydrogen sulphide gas (H_2S), quantities of water vapour, water droplets and ice crystals, and of ammonia vapour, droplets and crystals. The reddish-brown coloration of the belts and other hues commonly observed are now believed to be probably due to the presence of molecular sulphur and polysulphides of ammonia.

Interpretation of Observed Features

Despite the large amount of observational evidence about the planet that is now available, and the increasingly refined 'models' of its internal constitution produced by the theorists, it is still extremely difficult to define the kinds of physical activity that are giving rise to the many observed phenomena. Clearly we can regard the outermost layers of the planet as an 'atmosphere' and the belts and zones as a cloud-system. That the clouds should be drawn out into currents parallel to the equator is entirely predictable, due to the planet's rapid rotation. It must be realized, however, that the gaseous outer layers of Jupiter must be extremely viscous, so that motions within them will normally be of a fairly slow nature.

Although the normal surface temperature is so low – about 150°K – it has been discovered in recent years that the temperature of the planet is very variable, and there are sometimes localized 'hot spots' with temperatures rising to as much as 300°K.

Recent studies in the United States have shown that the cloud movements in the equatorial region of Jupiter show many of the characteristics of tropical cloud phenomena in the upper atmosphere of the Earth, albeit slowed down by the low temperature and high viscosity.

When we consider the long-lived features of the planet, however, such as the Great Red Spot and the South Temperate white ovals, it is tempting to believe that they must represent something more permanent than a cloud formation. It is difficult to conceive of a 'solid surface' of Jupiter as such on the basis of the gaseous constitution now proposed for the planet. The nearest to a solid surface in the terrestrial sense is probably a *layer* of significant thickness, within which small-scale motions are rapidly damped by the depth-dependent increase in viscosity, and below which the gaseous mixture is so compressed that it behaves as a solid mass. In any case it is difficult to envisage features on a solid surface, rotating at a uniform rate, being connected with observed features which are subject to such erratic movements as the Red Spot. This probably accounts for the long-held concept, mainly developed by Peek, of the Red Spot as a 'raft' of ices floating in the Jovian atmosphere; this idea is no longer seriously considered, however. Instead, it is now believed by most planetary astronomers that the Red Spot – and indeed many of the other discrete features observed on the planet – are only the manifestations at the visible surface of some feature or activity at a lower level (as was maintained by a few people, including the writer, many years ago).

One interesting theory to explain the Great Red Spot was put forward by Raymond Hide, a distinguished English meteorologist: Hide suggested that the Red Spot was the effect of a *Taylor Column* (a column of stagnant gas, centred over a projection or hump on the planet's 'surface' and moving through the surrounding gaseous layers as they flow past). This suggestion has found favour with many astronomers, but many others disagree with it – notably G. P. Kuiper, who does not believe that a Taylor Column could exist in the conditions obtaining in the outer layers of Jupiter.

Kuiper himself has proposed a different mechanism for the Red Spot: he suggests that it is an ascending, rotating column of gas – a sort of Jovian anticyclone – and has produced considerable supporting evidence from studies of Jovian cloud movements to account for its erratic motion on a purely meteorological basis.

If Kuiper is right, possibly the South Temperate white ovals and the large, bright ovals sometimes seen in the Equatorial Zone can be explained in a similar manner; if Hide is right, perhaps they are all caused by Taylor Columns. That such spirited debates are currently taking place indicates the greatly increased interest in the planets among professional astronomers, caused largely by the space programmes. Far from being a dead subject, of interest only to the amateur observers who devotedly study the planetary surfaces, the piecing together of a picture of their interiors is a continuing and absorbing story, full of discovery and excitement, to which new chapters may very well have been added even by the time this article appears in print.

The Tides

HENRY BRINTON

Every schoolchild learns something about the tides. Unfortunately for those who teach them, it is practically impossible to find a simple explanation. One standard book on astronomy, often reprinted and by a distinguished astronomer, is just wrong. Several encyclopaedias and books say, somewhat baldly, that the tide-raising force is inversely proportional to the cube of the distance from the Moon – a statement which happens to be untrue, though it is a fair approximation in the case of our particular system. Others deal obscurely with the concept of centrifugal force, which scientists dislike, and which can easily lead to a wrong result. Finally, several standard works offer a diagram of the tidal forces similar to that in fig. 3; but with an explanation which taxes the mathematical capacity of less skilled readers.

The easiest way to visualise the tide-raising forces is to remember that all celestial bodies are in 'free fall'; that is to say they offer no resistance to any of the forces acting upon them. Each of these forces can be considered in isolation. Thus the orbit of the Moon is made up of its constant velocity (considering the orbit as a circle) along a tangent, at right angles to which it is accelerating towards the Earth. These motions, which can be easily calculated separately, combine to produce the actual orbit. To understand the cause of the tides we have only to consider one motion of the Earth in relation to the Moon and another in relation to the Sun.

If we care to think first of the tide-raising force due to the Moon, we can consider what would happen if we ignored all other motions and thought only of the two bodies –

that is to say, the Earth and the Moon – falling freely toward one another. Let us further merely think of the Earth falling toward the Moon. Any particle in the Earth is subject to the pull of the Moon. The amount of the pull, if we take a particle of unit mass, will be MG/d^2, where M is the mass of the Moon, G the universal constant of gravitation, and d the distance of the particle from the Moon.Those particles which are solid will have to move in unison, and will be governed by the average pull – equal to that on a particle at the centre of the Earth.

A glance at Figure 1 will show that a drop of water, which can move freely, at point N will be subject to a pull greater than the average, and will therefore be subject to a greater accelerating force than the average, though the Earth's gravity will prevent the water leaving the solid surface Water round this point, therefore, will bunch up. At the point F, the opposite will happen. The acceleration at this point will be less than the average, and the water in that region will tend to get 'left behind' and will bulge away from the Moon.

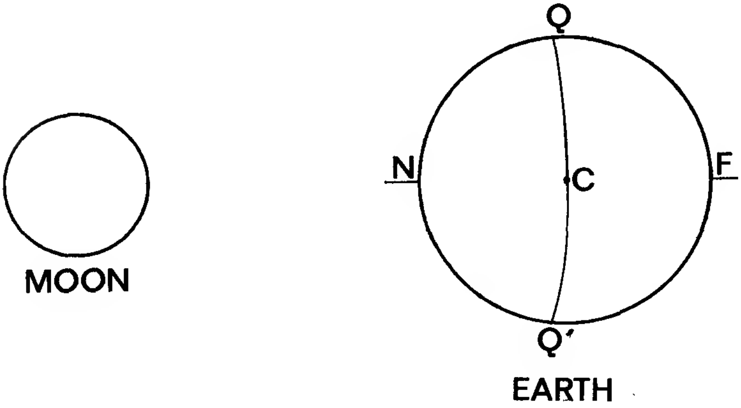

Fig. 1

The difference in the force at the points N and C – that is to say, the tide-raising force – is very small. It can easily be calculated. Using the same symbols, and taking r as the radius of the Earth, it is $$MG\left(\frac{1}{(d\text{-}r)^2}-\frac{1}{d^2}\right)$$

If we ignore those terms which are comparatively insignificant, the denominator reduces to d^3: thus $2GMr/d^3$. In other words, the tide-raising force is proportional inversely to the cube of the distance of the Moon from the Earth; the statement made in many reference books. Two points, however, should be borne in mind. Though the approximation is fairly close, it *is* only an approximation. In the second place, it is an approximation which applies to a particular system. It arises because the distances of the Sun and Moon from the Earth are great compared with the radius of the Earth, and the situation would not be the same with other systems.

Another way of looking at the tide raising force is in terms of statics. If we take any point O between Q or Q′* and N (Fig. 2) the attraction on a drop of water is towards the centre of the moon along OM; but only part of this attraction is available for tide-raising. The tide-raising force is this force less the amount of the average pull at the centre of the Earth, along CM. To find the direction of the tide-raising force and its quantity we divide the force along OM into two components, one along OR, parallel to OM, and the other at right angles, along OP. From the force along OR we need to deduct the average pull at C, leaving a shorter vector. We then recombine this residual vector with that along OP, and get a vector along OS, which represents the actual tide-raising force. (The drawings are diagrammatic, and the vectors not proportional to the lengths of the lines, but they lie along them.)

At Q and Q′ there is substantially no force parallel to CM, because QM = CM; but there is the component of QM which is directed towards the centre of the Earth. On the far side of Q and Q′, there are similar forces which are negative, representing tide-raising forces away from the direction of the Moon. The total result is as shown in Figure 3.

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*Strictly speaking, the 'mid' points, where the attraction at the surface of the Earth is the same as at the centre, are not at Q and Q′, but a little nearer N on the arc of a circle whose centre is the centre of the Moon, and which passes through the centre of the Earth as in Fig. 1.

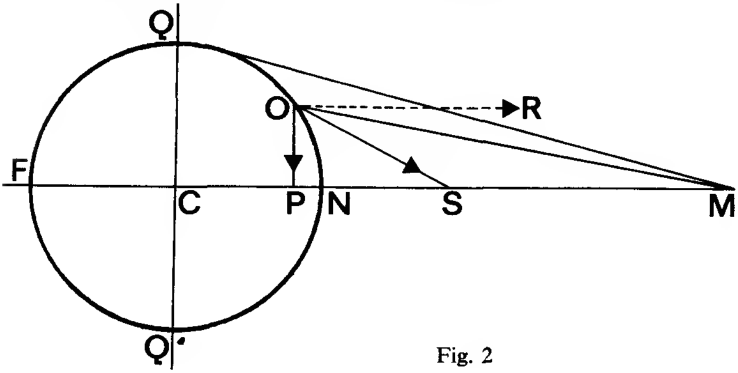

Fig. 2

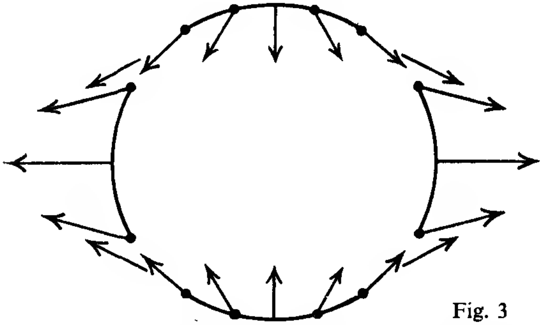

Fig. 3

As we have said, and as can be seen from the equation, the tide-raising force is very small: so small, indeed, that if we think only of the forces at the point nearest to and furthest from the Moon, they would raise no significant tide at all. The whole pull of the Moon on the Earth amounts only to 0·0033 dynes as against 981 dynes for the surface gravitation of the Earth. The maximum tidal force is only about one-thirtieth of the Moon's pull: that is, about 0·0001 dynes! At the sub-lunar or opposite point, the liner *Queen Mary* would weigh something under ten grammes less, due to the Moon's pull – hardly a significant difference with an 80,000-ton ship (8 x 10^{10}gm).

At first sight, it is difficult to see how these minute forces can raise any significant tide. One factor is that the effective tidal forces are, in places (Fig. 3) tangential, and in other places there is a tangential component. These components are moving the drops of water at right-angles to the terrestial gravitational pull, and not, therefore, having to act against it. Moreover, at the mid points the force is downwards, and so tending to squeeze the water towards the points N and F. Even so the tides raised are small. In the deep ocean they only amount to a couple of feet or so. The huge tides in places like the Bay of Fundy are the result of this deep-ocean wave washing up on the shallow coastal shelf or being concentrated by converging coast-lines.

Another tidal phenomenon which needs to be accounted for is the fact that high water occurs well after the terrestial spot concerned has passed the sub-lunar, or opposite, point. This is because the tide, which is effectively a huge wave, will move at the velocity dictated for a wave by the depth of water concerned. Since the velocity is always less than the velocity of the rotation of the Earth, the tide gets left behind*. The actual tides are the result of complex hydro-dynamic forces.

Many factors combine to complicate the calculation of the tide at a particular place or time. Of the direct forces, allowances have to be made for whether the Moon is near perigee or near apogee, since the orbit is somewhat eccentric, and the force varies as the square of the distance. There is, too, the question of the relative declinations of the Sun and the Moon, which will cause the directions of their respective pulls to vary. It is essential, however, to remember that the tides are a dynamic phenomenon, and that as well as their own momentum the actual tides are greatly affected by factors such as wind – which, particularly in an estuary, can cause marked variations in the height of a particular tide. Even variations in atmospheric pressure have their effects. In places, one can sometimes get an oscillating tidal effect, where, at the nodal point, there may be no rise at all even through there are considerable tides on either side.

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*The water would have to be a consistent 13 miles deep for the tidal wave to keep pace with the apparent movement of the Moon, which causes the sub-lunar point to move continuously.

The influence of the Sun on terrestial tides is less than that of the Moon, and can be calculated separately. The actual gravitational pull of the Sun on the Earth is much greater than that of the Moon.* As, however, it is the difference of the pull at the centre of the Earth and at the sub-solar point which constitutes the tide-raising force, the solar tide is less than the lunar one. Naturally, the total tide is due to the combination or opposition of the solar and lunar tides. When the Sun, Moon, and Earth are in line, at the full and change of Moon, the tides reinforce one another, and there is a high or 'spring' tide. When the three bodies are at right angles, at the first or last quarter of the Moon, the tides are 'neap', and have a lesser range.

There is another and permanent high tide, if it can be properly so called, at the equator. Here the convenient fiction of centrifugal force explains the phenomenon most easily. Since the Earth is rotating about its axis, there is a palpable effect tending to make the water at the equator heap up there, due to centrifugal force. Of course, the effect can also be explained in conventional terms. If one wishes, one may even say that the water at the equator, like any other form of matter, weighs less than it does at the poles. Calculating the effect is complicated by the fact that, owing to the flattening of the Earth at the poles, a particle there is closer to the centre of the Earth than is a particle on the equator, and so the attraction also is greater. In fact, the two effects reinforce one another. The difference in weight is therefore due both to the rotation of the Earth and to its spheroid shape.

This may have seemed in the nature of a digression; but it is important to stress that tides refer to other things besides the movement of water in the terrestrial seas. In fact there was a theory at one time, supported by Sir James Jeans, that the planets themselves were the effects of tides. The theory is no longer accepted in this context; but there is no reason to suppose that planets elsewhere may not have been formed in accordance with Jeans' theory. This suggested that long ago a star passed in closed proximity to the Sun, in which it naturally raised huge tides. Eventually a portion of the Sun might be drawn right away from the main body. The separated portion might then condense under gravitational forces into discrete lumps of matter, forming planets which would be captured and would orbit the Sun.

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*The pull of the Sun is nearly 0·6 dynes, far greater than that of the Moon. The tide-raising force, however, is that force multiplied by twice the Earth's radius and divided by the Sun's distance: that is to say 0·00005 dynes, or 5/11ths of the Moon's attraction.

Apart from such possible events in the cosmos, it must certainly be true that close binary stars raise large tides in one another. These tides will have the effect of slowing down the mutual rotation and, in the end, causing the binary pair to collapse into a single star. The Earth itself is having its rotation gradually slowed down by the effect of the tides, so that each hour is longer than the last. The amount is small in human reckoning – about a tenth of a second per century; but over periods judged on a cosmic scale, this tidal effect is of more than trifling significance.

So far as our little world is concerned, it has been suggested that the tides might eventually produce a most dramatic effect. It is not quite correct to say that because of its rigidity, the solid body of the Earth is unaffected by the solar and lunar tides. Technically, there are small tides in the land masses as well as in the seas. Similar tides are caused by the Earth in the body of the Moon. Though the Moon is at present getting further from the Earth, it will later begin to approach the Earth. As it does so, the tidal forces will increase. In time the Moon would get so close, within what is called the Roche limit, that the tidal force would tear it to pieces! However, it seems likely that before this can happen both the Earth and the Moon may have been destroyed by changes in the Sun.

Stellar Evolution

IAIN NICOLSON

One of the major problems of present-day astrophysics is to provide a detailed description of the entire life cycles of stars. Although current theories are quite satisfactory in many respects, and a great improvement upon earlier ideas, there are still many awkward aspects of stellar evolution which are currently taxing the minds of theoreticians. Until the post-war era, observational data relevant to the problem was restricted to work done in visible light, but nowadays, with the development of newer branches of astronomy, in particular radio and infra-red astronomy, considerably more information is available, particularly on the early and late stages of stellar life cycles.

A very convenient way of displaying observational data on stars is the Hertzsprung-Russell Diagram, which has been in use since 1914. The diagram consists of a plot of the absolute magnitude (M_v) (apparent magnitude at a standard distance of 10 parsecs – 32,6 light years – from the Sun) of stars against their surface temperatures or, strictly speaking, against the logarithm of effective surface temperature. Any star which has a particular absolute magnitude and a particular temperature can be represented by a point on the diagram. The Sun, for example, with $M_v = 4{\cdot}7$ and a surface temperature of about 6000°K lies near the centre of the H-R diagram depicted in Figure 1. Furthermore, the absolute magnitude of a star is closely related to its luminosity, i.e., the total amount of light being emitted at its surface, and so M_v may be replaced by luminosity, L, on the vertical axis. The surface temperature, likewise, is closely related to the spectral class (a classification of stars according to the detailed structure of their spectra), and

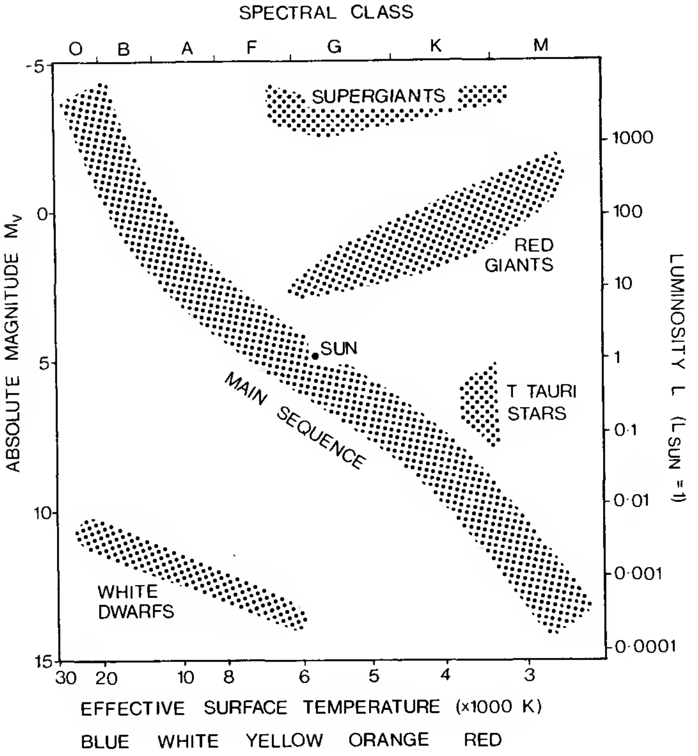

Fig. 1

also to the colour index (a measure of the colour of a star obtained by measuring its brightness at different wavelengths) and so either of these quantities may be used on the horizontal axis. In simple terms, a star such as the sun has spectral type G, corresponding to its temperature of 6000°K, and to the eye appears yellow. Very hot stars have spectral type O or B, and appear blue in colour. Stars which are cooler than the Sun have spectral type K or M, and appear orange or red to the eye.

If we look at a large sample of stars and give them positions on the H-R diagram, then we find that stars are not distributed at random all over the diagram. Far from it; stars seem to be found by and large in a few well-defined regions of the diagram. Of particular interest in an elementary description of stellar evolution are three prominent regions; the *main sequence*, a densely populated band of stars sloping from top left to bottom right in the diagram, the *red giants* in the upper right, and the *white dwarfs* in the lower left. The Sun itself is found to lie on the main sequence.

The terms 'giant' and 'dwarf' perhaps require a little explanation. Stars which have the same colour, i.e. essentially the same surface temperature, emit more or less the same amount of radiation *from unit area of their surfaces*. Now, if we find two red stars which have the same surface temperature, but one has a much higher luminosity than the other, then we can argue as follows. Since the temperatures are the same, then both stars must be emitting the same quantity of radiation per unit area. If one star is considerably more luminous than the other, then the total amount of radiation being emitted from its surface is greater than that being emitted by the other; consequently the surface area of the brighter star must be greater and so (since stars are spherical bodies), the diameter of the brighter star must be considerably greater than that of the fainter star.

The stars in the red giant region have luminosities up to 1000 times greater than main sequence stars of the same colour, and are thus very much larger, hence meriting the title 'giant'. The best-known example of a red giant is perhaps Betelgeux in the constellation of Orion, whose radius is so great that if it were placed where the Sun is now, the Earth's orbit would be contained within its globe. At the other end of the scale, the white dwarfs have high surface temperatures, as their colour suggests, but their luminosities are very low compared to main sequence stars. Consequently their radii are small (comparable with the Earth in some cases) and their densities very high, being of the order of 10^5 grams per cubic centimetre ($g\ cm^{-3}$) compared to $1{\cdot}3\ g\ cm^{-3}$ for the Sun.

It is now pretty well established that these types of star represent various stages in the evolution of individual stars, but an understanding of the way in which this evolution takes place only became possible with the advancement of nuclear physics. Early ideas on stellar evolution suggested that stars radiated purely as a result of contraction under gravitational forces. Thus a star was thought to form from a cloud of gas, begin life as a red giant and, as it heated up due to contraction, so it would move from right to left on the H-R diagram. Eventually, the star reached its maximum possible temperature and began to cool down and drop in luminosity. It therefore moved from upper left to lower right in the H-R diagram, finally ending up as a cold, non-luminous body. Although superficially attractive, this theory suffered many drawbacks. It did not, for example, provide any explanation of white dwarfs. The most serious objection to this idea, however, was the realization that 'stars' which shone solely as a result of this process could not continue to shine for very long. The Sun, for example, could only live for the order of ten million years as a result of this process, whereas a considerable body of evidence suggested the age of the sun was several thousand million years. Clearly, then, this simple account does not suffice.

Current theories suggest the following. Initially, stars condense out of clouds of gas and dust, contracting under gravitational forces and heating up as they do so. There seems little doubt that this is indeed what happens, but the precise mechanism by which these infant stars, or *protostars*, do form from gas clouds is by no means fully understood; there are several approaches to the problem under investigation at present, none of which as yet has overcome all the theoretical difficulties. However, these problems do not concern us too far here, as stars clearly do exist! In the early stages, then, protostars are large cool objects, likely to be surrounded by clouds of gas and dust, and so will emit most of their radiation in the infra-red region of the spectrum. Current investigations in infra-red astronomy appear to indicate the existence of such objects and, in particular, an infra-red source in the Orion Nebula (M42) seems to be a protostar in the process of contraction. If this is the case, then the object will be seen to evolve noticeably in the next decades, and so there may be an excellent opportunity to test ideas on star formation by direct observation.

As the protostar contracts, its temperature and luminosity increase, and so if we were to plot its development on the H-R diagram, then the protostar would appear far on the right, moving towards the main sequence. When conditions in the central regions of the star are suitable, i.e., when temperatures exceed 10^7°K, then nuclear fusion reactions similar to those which operate in the hydrogen bomb can take place whereby hydrogen is converted to helium with the release of large quantities of energy. With the onset of this 'hydrogen burning' phase the star reaches a stable condition where the energy supplied by these processes in the core of the star is sufficient to counterbalance the gravitational forces trying to contract the star further. This stable state corresponds to the star reaching the main sequence, and provided that the star can maintain a constant supply of energy from its core, it will remain more or less stationary in the H-R diagram at its allotted point on the main sequence. The T-Tauri semi-regular variable stars whose position on the H-R diagram is indicated in Figure 1 are thought

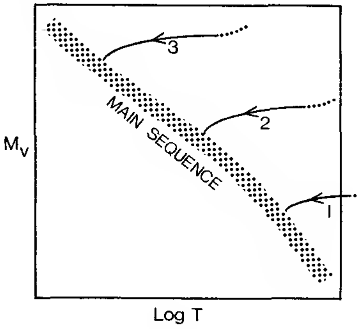

Fig. 2

to be a class of young stars which have not yet reached the main sequence proper.

The position which a star attains on the main sequence depends upon mass and chemical composition, but in particular there is a fairly well-defined relationship between the luminosity of a star and its mass. This *mass-luminosity relationship* indicates that the luminosity of a star is proportional to the third or fourth power of its mass. Thus a star ten times as massive as the Sun is likely to be at least a thousand times brighter than the Sun. The way in which three stars of different masses evolve towards the main sequence is indicated in Figure 2. Protostars with masses less than about 0·1 solar masses cannot attain the conditions necessary for fusion to occur, and so do not become fully fledged stars at all.

Stars spend the major part of their lives on the main sequence, but the time a particular star spends there – its main sequence lifetime – again depends upon its mass. It is thought that a star will remain on the main sequence until about 10 per cent of its mass has been converted into helium, which congregates in the core; and clearly the length of time it takes for a star to reach this state depends upon the rate at which it is producing energy (i.e., essentially upon its luminosity) and the amount of matter contained in the star, i.e. its mass. From the mass-luminosity relation it is apparent that the more massive a star, the faster it will consume fuel, and therefore the shorter will be its main sequence lifetime. For example, the Sun is expected to remain on the main sequence for some 10^{10} years (having been there now for about 5×10^{9} years); but a star ten times the mass of the Sun and therefore at least a thousand times more luminous is likely to exist on the main sequence for only about one hundredth of the Sun's main sequence lifetime. Exceptionally bright blue O-type stars may spend only a few million years in this stage, whereas very faint red main sequence stars, considerably less massive than the Sun, may exist for 10^{11} years or more.

When a star reaches the embarrassing stage of having its core clogged up with helium, then it has difficulty in producing enough energy to support itself. In particular, the central temperature will be insufficient to allow nuclear reactions to proceed using helium as fuel. Under these circumstances the core is not able to support the weight of the rest of the star and begins to contract, so raising the temperature sufficiently in a shell of matter surrounding the core for hydrogen burning to continue. As this stage of evolution proceeds the energy produced is sufficient to cause the entire star to expand and move away fairly rapidly from the main sequence along a track such as those indicated for the three stars in Figure 3. For a star such as the Sun, luminosity will increase by a factor between 10^2 and 10^3 by the time about 50 per cent of the star's mass is contained within the boundary of the burning shell. After this, further contraction of the core takes place, sufficient to raise the central temperature to a level at which energy can be produced by the conversion of helium to carbon. By this time the star has evolved fully to the red giant region. The precise way in which a star becomes a red giant depends upon its internal constitution and upon its mass, and it should be emphasized that the above is a rather sketchy account particularly applicable to stars not too different from the Sun.

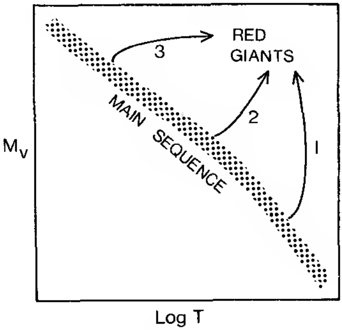

Fig. 3

While these stages in stellar evolution are reasonably well accounted for at the present time, the later stages are subject to considerable debate. It seems probable that a star comparable with the Sun will, after the red giant stage, move right to left in the H-R diagram and with further energy production by nuclear processes no longer possible contract to the dense white dwarf state. The star then radiates away its residual energy over periods of the order of 10^9 years and ends as a cold, dark body sometimes known as a black dwarf.

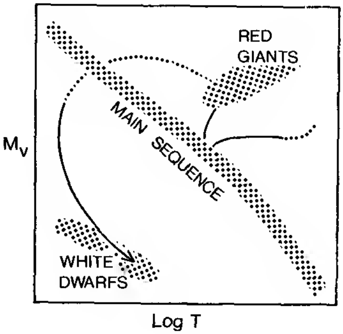

Fig. 4

However, it has been shown that stars whose mass is greater than about 1·4 solar masses cannot become white dwarfs directly, this critical mass defining the Chandrasekhar limit. There is, however, considerable evidence for the existence of processes whereby stars can lose mass; novæ, planetary nebulæ, and supernovæ are all fairly well established examples of mass–loss processes of varying degrees of severity. If, then, a massive star can lose sufficient material to bring its mass below the Chandrasekhar limit, it can in principle become a white dwarf. In massive stars it seems likely that successive reactions can take place until iron is being produced in the core, with various other processes going on in concentric shells right out to the outer layers in which a mixture of hydrogen and helium still exists. Once iron is produced no further fusion processes are possible and the star may then collapse. If the mass of the star after any mass-loss processes is still greater than 1·4 solar masses, then the star seems likely to collapse to a super-dense state where the nuclear particles, in particular electrons and protons, are combined to form a body composed almost entirely of neutrons. Under these circumstances, the density of the star may exceed 10^{12} g cm^{-3}. In other words, a one-inch cube of neutron star material would weigh ten million tons. The star itself would shrink to a radius of only about ten kilometres These neutron stars were predicted as early as the 1930s, and have now been identified with the *pulsars*, which were first discovered in 1968.

Pulsars were first detected as radio sources whose principal characteristic was the regular emission of pulses of radiation every second or so (the fastest pulsar known at present emits a pulse every thirtieth of a second), but since then some of the radio pulsars have been shown to pulse in visible light and x-rays also. It is thought that neutron stars will possess strong magnetic fields, and so are likely to be strong radio sources. Furthermore, because of their very small radii, and conservation of angular momentum they will be rotating very rapidly on their axes, and so will send pulses of radiation towards us at each revolution. The best known example of a pulsar lies at the centre of the Crab Nebula, which is known to be the remnant of the supernova observed in 1054. This correlation lends strength to the argument that pulsars are the collapsed remnants of massive stars.

There is, however, one further possibility which remains for massive stars. It appears that if a star or stellar remnant is more than about twice the mass of the Sun, then the star may collapse beyond even the neutron star state. It is thought to enter a state of gravitational collapse which cannot be halted by any known physical force, so that in principle it could contract to a point of infinite density. Before this embarrassing state of affairs occurs, the gravitational field of the contracting star would become so powerful that no radiation could escape from its surface (the star is then said to have contracted within its Schwarzschild Sphere). The star would thus disappear from view and could not be detected by any optical means. Such an object is known as a 'Black hole'. So far, it has not been possible to observe any such object with certainty, but it does seem as though it might be possible to detect such objects as a consequence of their strong gravitational fields acting on surrounding matter, and considerable efforts are being made in this direction.

The above review is of necessity rather sketchy, and makes no mention, for example, of the evolution of double and multiple stars. However, to summarize the broad outlines of present ideas on stellar evolution, it is worth returning once more to the Hertzsprung-Russell diagram. Clearly, since even the most massive stars take millions of years to evolve, the astronomer cannot follow any one star through its life cycle. He can, however, look at a cross-section of different types of star at different stages of evolution and piece together life cycles in this way. The H-R diagram for a large sample of stars is an indicator of the length of time stars spend in various evolutionary phases. Thus the majority of stars are seen to lie on the main sequence because individual stars spend the greatest proportion of their lives on the main sequence. Likewise, few stars are seen between the main sequence and the giant region, or white dwarfs region because the evolutionary process between these states is rapid on an astronomical time scale.

A star like the Sun begins life as a contracting gas cloud, which increases in temperature until nuclear reactions commence in the core. It then remains on the main sequence until it has used up its hydrogen fuel reserve in the core, whereupon it rapidly becomes a red giant. Thereafter its future is somewhat uncertain, but it seems likely to become a dense white dwarf and then cool to insignificance. A more massive star may not reach the white dwarf stage, but under certain circumstances may become either a super-dense neutron star, or possibly collapse into a black hole.

We are now entering a period in astrophysics where to a much greater extent than ever before, theories of stellar evolution can be subjected to the test of observation. New techniques in observation and theory should lead in the coming years to very significant advances in our understanding of the complex way in which stars organize their lives.

The Enigmatic Wolf-Rayet Stars

DAVID A. ALLEN

A failing of many introductory texts is their tendency to overstate the bounds of our knowledge. Thus in astronomical circles you will find books which paint a very rosy picture of our understanding of stars. There are young stars and old stars, blue stars and red stars, and by and large it is now true to say that we have a pretty good feel for why some are red when others are blue, and what changes a star undergoes from youth to old age. There remain, however, serious gaps in our knowledge, gaps that so often are glossed over. One such gap is the formative years of a star's life. It is easy to prove that stars cannot form; it is more difficult to demonstrate how they form or what they look like when they do.

The Wolf-Rayet stars represent another weak point in our understanding. The story began over a century ago. Astronomers of that era had taken the first steps towards stellar spectroscopy. They had found that the light from stars – like that from the Sun – when passed through a prism gave a continuous spectrum intercepted by narrow dark lines. From star to star the differences in the intensities of these dark lines are used to define the spectral types so familiar today. Letters of the alphabet were originally introduced to distinguish types of spectra. We have now arranged these spectral types into what we regard as a logical progression, thereby shuffling the lettering system devised last century to form the well-known Oh Be A Fine Girl . . . sequence. Stars at the OBA end are hot and blue; those at the MRNS end are relatively cool and red. This is the part we now think we understand.

But in 1867, in the midst of all the turmoil concerning spectral types, two observers from the Paris Observatory announced the discovery of a completely new type of stellar spectrum. They had found three stars in Cygnus whose spectra comprised very broad *bright* lines. They could detect no narrow dark lines at all. Presently more of these stars were found and were named, in their honour, Wolf-Rayet stars. In the spectral scheme they were given the letter W (sometimes WR). This is the W so often omitted from the beginning of the OBAF sequence.

Spectroscopy became a respected branch of astronomy (prior to this event astronomers believed that the only outstanding task in their profession was the more accurate measurement of the apparent positions of the stars). Techniques improved, and with them Man's understanding of the narrow dark lines in a star's spectrum. Questions concerning the relation of these dark lines to the temperature and dimensions, even the age of a star, were raised and slowly answered. At length attention was turned to the Wolf-Rayet stars. The known peculiarities of these objects at once began to multiply.

No two Wolf-Rayet stars have the same spectrum. Since Man in all his wisdom cannot accept such a thing, they are generally subdivided into two sets, each further subdivided on the basis of small differences in certain of the bright lines. The major division concerns us here; the further numbering of each from 5 to 8 (1 to 4 have been lost in the vastness of history) is a mere complication. With the inevitable few exceptions, Wolf-Rayet stars split neatly into a nitrogen and a carbon sequence. The nitrogen sequence – WN stars – have, primarily, bright lines attributed to the elements hydrogen, helium, and nitrogen. The carbon sequence – sadly named WC – have, in addition to the ubiquitous hydrogen and helium, lines of carbon and oxygen. There are no nitrogen lines in a WC star, and vice versa.

There *are* dark lines in Wolf-Rayet spectra, but they are broad and weak, and appear not at the normal wavelengths but Doppler shifted to the blue. Hence we deduce that material in front of the stars is moving towards us, material that has been ejected by the star itself. Moreover Wolf-Rayet spectra show no significant changes with time; these stars are continually losing mass. When we work out the velocity of expansion of the material from the stars we find it to lie in the range 500-3000 km/sec. This is exactly the behaviour we see in the most violent novæ. Novæ are regarded as impressive phenomena, yet they explode only once or twice in their lifetimes. The Wolf-Rayet stars are in continual nova-like eruption! It has been estimated that the average Wolf-Rayet star takes only two or three million years to lose its own mass. By astronomical standards this is so extremely rapid that the Wolf-Rayet phenomenon must be short lived, and it is likely that many 'normal' stars pass through a brief Wolf-Rayet phase at some time in their careers, probably near either the beginning or the end.

There are about 150 Wolf-Rayet stars known in our own Galaxy and over 50 more in the Large Magellanic Cloud. A large proportion of the brighter ones lie in the constellation of Cygnus. Since they are so readily detected spectroscopically it is probably safe to say that we know of almost all those brighter than about magnitude 12. Thus Wolf-Rayet stars number fewer than one in a million. Their distribution suggests that they are young. They concentrate in the spiral arms of our Galaxy, they tend to be members of associations of O and B stars, objects known to be relatively young, and a high proportion of them are binaries in which the companion is an O star. From the binary motion we deduce their mass to be about five times that of the Sun. By assuming that the O stars with which they are associated are normal, we determine their luminosities to lie between 500 and 20,000 times that of the Sun. Compared to normal stars of the same mass they are very over luminous, though not to the same extent as are novæ.

The W spectral class is often placed before O on the normal spectral sequence. This is valid if we consider the one dimensional classification according to luminosity alone. However, the mass of a typical Wolf-Rayet star corresponds more closely to that of a B star, i.e. to a position after the O stars. Like the white dwarfs, Wolf-Rayet stars are objects that do not belong on such a classification scheme.

A better scheme – a two dimensional one – groups stars according to both surface temperature and luminosity. In pictorial form this is the Hertzsprung-Russell diagram. For most stars there is a direct relationship between luminosity and temperature. Such stars lie on a curved line – the main sequence – on the H-R diagram. Given, say, the temperatures, we can accurately predict the luminosity of a main sequence star. White dwarfs do not conform to this relationship; on the H-R diagram they do not lie on the main sequence. We guess that Wolf-Rayet stars too lie off the main sequence. We cannot tell, however, since we do not know their surface temperatures.

Visually Wolf-Rayet stars appear blue or white. This suggests that they are one of the hottest types of star. However, the colour cannot be directly interpreted as a temperature because most of the light we see is in the bright lines. In just the same way, we cannot say that a mercury street lamp is hotter than a sodium lamp because it appears bluer.

Alternatively we can estimate the temperature from our understanding of the bright lines themselves. The temperature we then deduce refers not to the surface of the star, but to its outer atmosphere. This atmosphere is a particularly violent and turbulent place and is quite unlike that of any other type of star. This turbulence is responsible for the breadth of the bright emission lines and presumably for the high rate at which material is being blown away. In fact we see so little light from the underlying surface of Wolf-Rayet stars that we cannot classify them in any meaningful way. They may not even possess true surfaces in the form we are used to seeing in the Sun. Thus it may seem convenient to place them at the beginning of the (one-dimensional) spectral sequence, but it is more honest to omit them altogether.

There have been attempts to explain the differences between WC and WN stars on the basis of conditions (such as temperature) at the surface of the stars rather than by any gross differences in composition. There is a certain elegance about this approach for we then have to account for the existence of only one type of peculiar object. On the other hand there are more differences than the carbon/nitrogen imbalance that distinguish the two subdivisions. For example, those Wolf-Rayet stars that lie in association, or are binaries, are more often members of the nitrogen sequence. A more recent piece of evidence comes from infra-red photometry. We have found that most WC stars are surrounded by dust clouds (the dust presumably originates in the material expelled, and may be graphite particles) which radiate at infra-red wavelengths. WN stars show none of the infra-red dust emission. Whichever theory we invoke to explain the spectral differences must also account for the dust shell preference of WC stars. The simple abundance theory – that WC stars have more carbon and WN stars more nitrogen – can account for this, since nitrogen and its compounds do not readily form dust, whereas carbon does.

Given that the Wolf-Rayet stars are found in connection with hot young O stars and that they must be short-lived phenomena, it is tempting to regard them as a formative phase in the development of O or B stars, a stage, perhaps, at which the condensing star finds it has too much mass and proceeds to shed its excess. When Wolf-Rayet stars occur in binaries, the O or B companion is always the more massive component. Since massive stars evolve faster, we conclude that the Wolf-Rayet stars are at an earlier stage of their evolution than the O stars, in apparent confirmation of this view. All the indications are that conventional Wolf-Rayet stars are a phase in the development of O or B stars, much as T Tauri stars are a phase in the development of many cooler stars. One possible objection to this theory should be mentioned: there are no known Wolf-Rayet stars in the Orion Nebula where O stars are known to be forming. This is, perhaps, a problem that time alone can solve.

At this juncture we must digress to discuss the planetary nebulæ. It will be recalled that these are small, bright, and often circular or annular nebulæ. Their central stars are very hot. Current theories regard planetary nebulæ as the graveyards of late-type supergiants like Betelgeux. We know that the supergiants are losing mass – smoking gently from their surfaces. When the outer layers have been sloughed, the remaining core of the star contracts. The expelled material is heated by the central object and by collisions with atoms and molecules of the interstellar medium, and becomes the visible nebula; the remnant core forms the central star. Many of the central stars show no spectroscopic features at all. Those that do are often O stars. Why is a young O star at the centre of an old planetary nebula? It is not entirely unreasonable that the remnant core of an M supergiant should spectroscopically resemble an O star, although having different age and origin from 'normal' O stars.

There are, however, 16 well-attested cases in which the central star of a planetary nebula has a Wolf-Rayet spectrum. The Saturn Nebula, NGC 7009, is one example and the famous 'blinking' nebula NGC 6826 another. Both WC and WN spectra are represented. Now why is so young an object as a Wolf-Rayet star at the centre of an old planetary nebula? Could it be that at some stage the core of an M supergiant spectroscopically resembles so bizarre an object as a Wolf-Rayet star? We are forced to answer in the affirmative. The distribution throughout our Galaxy of planetary nebulæ closely parallels that of late-type supergiants, but is grossly different from that of young O and B stars or of those Wolf-Rayet stars that do not lie within planetary nebulæ. If, indeed, the core of a cool supergiant can evolve to resemble an O star, then it can pass through a Wolf-Rayet phase during that evolution. Our conclusion, in the absence of further evidence, must be that the Wolf-Rayet phenomenon arises when very hot stars pass through a phase in which dynamics dictate that they must lose mass. These hot stars may have formed recently in gaseous nebulæ or they may be the unstable remains of an old red supergiant.

If the last few paragraphs have seemed confused it is at least in part because our thoughts are that way. Any review of the Wolf-Rayet stars must leave more questions unanswered than it can solve. Such is the nature of Man's transient knowledge. It is a thorn in his flesh that the Wolf-Rayet stars do not readily conform to his simple models. The answers may lie just around the corner . . . or, more likely, in the *2073 Yearbook.*

Seyfert Galaxies

SIMON MITTON

Spiral and elliptical galaxies are huge systems containing thousands of millions of stars, as well as significant quantities of gas and dust, and Iain Nicolson described some of their properties in the 1972 Yearbook. The spectrum of the emitted light from the majority of galaxies closely resembles the spectra of the hottest and youngest stars within the galaxy. Carl Seyfert drew attention to exceptions from this simple picture when, in 1943, he published a list of spiral galaxies whose spectra did not conform to the general trend. Seyfert noticed that a small fraction – about one per cent – of all spiral galaxies have inconspicuous arms and extremely bright central regions. The radiation from these central nuclei is characteristic of a hot gas, and not at all like starlight. What are these strange objects whose light does not come from stars?

After Seyfert's initial study little further attention was paid to those particular celestial oddities. Then, in the late 1950s, the overwhelming problems associated with energy production in powerful radio galaxies sparked off a renewed interest in exploding and contorted galaxies. The discovery of quasi-stellar objects stimulated further research on the galaxies mentioned in Seyfert's paper as astronomers speculated that these relatively local systems might be quasars in slow motion.

Today there is no watertight definition of the term 'Seyfert galaxy'; in general they have a very luminous, compact, nucleus in which violent gas motions can be discerned, and relatively insignificant spiral arms. In all there are about two dozen objects presently classified as Seyfert galaxies, and they are currently the subject of vigorous research, as the modern astronomer applies advanced technology to squeeze more data from them. Ground-based optical and radio telescopes, infrared photometers carried aloft in jet aircraft, and x-ray detectors aboard satellites are all making measurements of the radiation sent out by Seyfert galaxies. Astrophysicists are particularly interested in examining compact galactic nuclei in as much detail as possible, because many of their properties look like scaled-down versions of those seen in quasars. They argue that it may be possible to build up a physical picture of the moderate activity in Seyfert galaxies, and then pass on to the extremely violent convulsions of quasars. However, even if it turns out that Seyfert galaxies are not directly related to quasars, they may still be important to the physicist: their prodigious energy requirements must be met by a process which is at present unknown, and which might call for a reformulation of parts of physical theory.

In describing the observations I shall refer mainly to NGC 1068, 1275, and 4151, as these are the brightest and most thoroughly studied of the Seyfert galaxies. They have redshifts of 0·0036, 0·018 and 0·0033 respectively, values which correspond to distances of about 30, 150, and 27 million light-years. Optical photographs show that their nuclear regions are a few seconds of arc in size, representing a linear diameter of perhaps a thousand light-years. Thus the remarkable phenomena of Seyfert galaxies are observed within comparatively small volumes.

Optical astronomers have deduced a considerable amount of information about the physical conditions inside Seyfert nuclei by taking high resoluton spectra with large telescopes. Such spectra show the conspicuous feature first noted by Seyfert: there are many bright lines due to emission from neutral and partially ionized atoms of oxygen, nitrogen, and neon. The presence of these lines immediately implies that the radiation does not come from stars, but is generated in a gaseous nebula which has low density and a high temperature. Astonishingly, for NGC 4151, there is not a shred of evidence to suggest that there are any stars at all in the nucleus! From the relative strengths of the emission lines it is possible to calculate the density and temperature of the gas clouds in the nucleus. According to John Oke and Wallace Sargent, the density for NGC 4151 is about 100,000 atoms per cubic inch, and the temperature is 20,000°K. Altogether there are estimated to be 200,000 solar masses of hot gas in the nucleus of NGC 4151. When the volume occupied by this mass of radiating material is calculated it turns out to be considerably smaller than the volume estimated from an optical photograph. Presumably this is because the gas is concentrated into small clouds and filaments with little material in between, rather than being spread throughout the entire volume.

The rapid movements of the nuclear gas clouds are especially interesting. In some compact galaxies the spectrum can be resolved to reveal two or three distinct systems of clouds rushing about with very different velocities. At the Kitt Peak National Observatory, Dr Roger Lynds has secured beautiful photographs in the red light of hydrogen of the NGC 4151 nucleus. His pictures reveal delicate structure and filaments in the nuclear gas. Intertwined fingers of gas are racing out from the centre at speeds of 2000 miles per second. The amount of kinetic energy needed to spark off a galactic explosion of such titanic grandeur greatly exceeds the energy released in typical supernova explosions. It is probable that the kinetic energy locked up in mass motion could be converted into optical emission through accidental cloud collisions. In this way the nucleus may be heated to high temperatures and the gases ionized.

To the experimental spectroscopist the precise shape of a solitary spectral line may conceal a wealth of subtle detail. Such is the case of the hydrogen line profiles in Seyfert nuclei, because they have very broad wings, and these pose perplexing problems for astrophysicists. Strangely, the hydrogen lines consist of two distinct parts: there is an intense central core which has a similar shape to the oxygen and neon lines, but on either side the line spreads out into very broad wings, as I have shown in Figure 1. There are two ways in which this unusual line

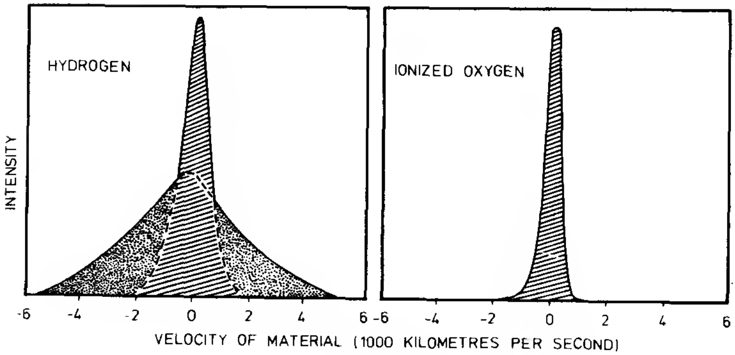

Fig. 1

profile might arise. One theory suggests that the emission process takes place in two differing types of nuclear cloud. The narrow core of the line is produced alongside oxygen, neon, and nitrogen in one sort of cloud, while elsewhere the broad wings are generated in regions which have large internal motions. (Random motion will always broaden line radiation, so that wide lines may be taken as an indicator of agitated motion.)

An alternative proposal suggests that the photons from the hydrogen have to travel through a heated ionized gas. In this case there is the possibility of a collision between a photon and a fast electron, with the result that the photon wavelength is altered. This process of electron scattering interferes with the oxygen and neon emissions to a far lesser extent than the hydrogen emission, so that only the hydrogen lines exhibit the broadening.

Many contributions to the study of Seyfert nuclei are made by astronomers who observe outside the visible range of the spectrum. Infra-red rays are absorbed by the Earth's lower atmosphere, and so jet-age astronomer Frank Low and his colleagues have to fly their telescopes in high altitude jet aircraft. As part of a programme to investigate exotic objects, they have discovered exceedingly strong infra-red radiation from Seyfert nuclei, arguably infra-red astronomy's most notable success to

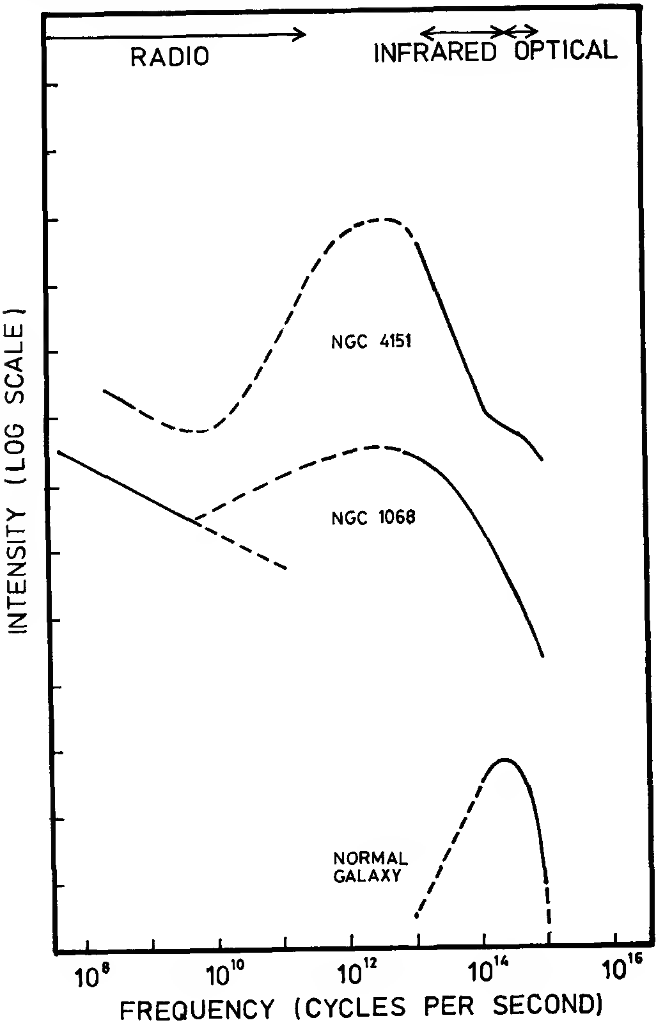

Fig. 2

date. The emission starts to increase sharply at a frequency of 10^{14} cycles/sec and then it peaks at 10^{13} cycles/sec (Figure 2).

What happens at shorter wavelengths is still a matter of speculation, but by the time we reach the high-frequency end of the radio spectrum it has fallen considerably in intensity. The infra-red peak represents an enormous luminosity: there is more energy in the far infra-red radiation from a single Seyfert galaxy than in the starlight of 500 galaxies like our own! Here, almost on our own doorstep, the infra-red astronomers have uncovered galactic systems whose ravenous demands for energy may well rival some of the quasars residing at the boundaries of the observable universe.

From a theoretical standpoint a significant feature of the infra-red luminosity of NGC 1068 and 4151 is that they vary on a time-scale of a few weeks. Fluctuations as rapid as these imply that the primary energy source for the infra-red emission must be less than a light–year in diameter, because short-period variations are limited to the time taken for a light signal to traverse the energy generation zone. The process underlying the huge infra-red luminosities of Seyfert galaxies is still a mystery. In order to explain the observations some theorists have developed a model which has two main ingredients: an intense source of ultra-violet light at the centre of the galaxy and a shell of dust enveloping it. The ultra-violet radiation emitted at the centre is absorbed by grains of dust, and these are consequently heated up to a temperature of about 1000°K. Thermal radiation from specks of dust at this temperature is most intense in the infra-red, as required by the measurements of the spectrum. The validity of this particular model depends quite critically on the radius of the dust shell enclosing the nucleus, and the current observations of rapid variability seem at variance with the theory. One way out of this difficulty is to suppose that the central source generates x-rays and not ultra-violet, because the modification to the theory slims down the size of the absorbing dust shell.

In 1971 space scientists trained their x-ray telescopes on to Seyfert nuclei, and achieved spectacular success. When the x-ray telescopes aboard the Uhuru satellite swung into action they found amazingly intense emission from the nucleus of NGC 1275; its energy output in the x-ray band is around 10^{45} erg/second, a figure which is comparable to the spendthrift dissipation in the infra-red. The observations may have far-reaching influence on the theories, because we now have firm evidence that there is a powerful x-ray source associated with the nuclei of both NGC 1068 and 4151. Previously the models have had to assume the presence of a photon generating machine in order to explain the ionization of the hot gas clouds and the infra-red emission. Perhaps it will shortly be possible to develop a more coherent picture of Seyfert nuclei, relying more on hard fact and less on the presence of mysterious sources of radiation.

For many years radio astronomers have studied the structures of radio sources in the neighbourhood of NGC 1275, which is but one member of a large cluster of galaxies in Perseus. The brightest radio source, 3C 84, is a compact, variable object at radio wavelengths; significantly it coincides with the nucleus of NGC 1275. Repeated outbursts of enhanced radio emission occur on time-scales of a few months, although there is no obvious correlation with the pattern of variability at other wavelengths. In 1968 a high resolution map of the entire cluster of galaxies around NGC 1275 was made by the One-Mile telescope at Cambridge, and this revealed complex radio sources apparently embedded within the rest of the cluster. Two of the galaxies, NGC 1265 and IC 310, possess sausage-like radio components which point directly away from NGC 1275. It seems as if the Seyfert galaxy is upsetting two of its neighbours, and activity in its tiny nucleus has triggered a protest in other galaxies one million light years away. One interpretation is that NGC 1275 is managing to interact with its neighbours, perhaps by blasting huge masses of cold plasma towards NGC 1265 and IC 310. When this material crashes into the galaxies it is excited through collisions to emit radio waves.

The latest spectroscopic analysis of the Perseus galaxies supports the notion that violent activity on a very large scale is a feature of the cluster. Guido Chincarini and Herbert Rood have measured the radial velocities of 49 member galaxies, and their results show that Perseus is unparalleled by any other cluster. Although the mean recession velocity of the galaxies is 5500 kilometres/second, the deviation from the mean is 1500 km/sec, and NGC 1265 is zooming away from its companions at 2200 km/sec. Large velocities such as these imply violent expansion of the whole cluster, and no doubt observers will be anxious to accumulate more data on this exceptional cluster dominated by NGC 1275.

It is difficult to present a coherent summary of the wide variety of phenomena now documented for these versatile galaxies. So far it is established that all well-studied Seyferts are prodigious infra-red sources, and at least two are powerful x-ray galaxies. According to a recent survey from the new Dutch radio telescope at Westerbork, eight Seyfert galaxies are detectable as radio sources, and one of these is certainly interacting with other nearby galaxies. Periodic explosions in the Seyfert nucleus blast débris into the surrounding regions, where there are many filaments of gas emitting the spectral lines, but few (if any) stars.

Theoretical ideas on the energetic processes in Seyferts, although largely speculative, are none the less of importance to physics in general. All models of Seyfert nuclei ultimately rely on the *ad hoc* existence of a primary energy source. Seyfert galaxies live for about 100 million years, and the total energy radiated at all wavelengths over this time is 10^{61} erg. Radio interferometers have shown that, in the case of NGC 1275, the core where this energy is poured out to the universe is less than one light–year across. The statements in the previous two sentences collide head-on: conventional concepts of nuclear physics are woefully inadequate in accounting for such a large energy output from such a miniscule region. Nuclear reactions inside the stars are less than one per cent efficient at transforming mass into energy, so that implausibly large star densities would be implied by a conventional interpretation of Seyfert phenomena.

Faced with a situation in which quasars, radio galaxies, and

Seyfert nuclei are putting increasing pressure on the laws of physics, theoreticians are inclining towards gravitational forces as the ultimate powerhouse of the universe. When a massive star exhausts its nuclear fuel and then starts to cool down there seems to be nothing to prevent an indefinite collapse under its own gravitational field. But collapse to what? The mass of the shrinking star is concentrated into smaller and smaller volumes, so that the gravitational acceleration at the surface becomes incredibly large. Eventually the attraction at the surface of the tiny star is so great that photons are unable to escape from the star's influence. These exotic stars which imprison their light are the mysterious black holes isolated from the rest of the universe.

The importance of collapsed matter, whether it be in the form of black holes or spinning pulsar-like objects, is that the free fall under a gravitational force releases large amounts of energy. One idea envisages a huge, rotating, black hole greedily gobbling up the surrounding stars and dust. The captured mass is not swallowed without a vociferous protest, and up to one-half the rest mass may be converted to energy as it disappears into the tremendously strong gravitational field. Admittedly the ideas being tossed around at present are unavoidably vague, and this is a situation which the observer can strive to improve. Only then shall we know if the Seyferts really are crying out to us to revise parts of gravitation theory.

Recent Advances in Astronomy

PATRICK MOORE

The 1960s saw many striking developments in astronomical science. In particular, quasars and pulsars were discovered, and there came the true beginnings of x-ray and gamma-ray astronomy. Moreover, men reached the Moon, and the first really successful planetary probes were launched. All in all, it was certainly the most spectacular decade of modern times; and it may well be that the 1970s will go down in history as a decade of consolidation rather than pioneer discovery. Yet they have begun in an exciting manner, and each year seems to bring its new quota of advances.

At the time when this article is being written (June 1972) the Apollo programme is nearing its end. As everyone will remember, Astronauts Scott and Irwin, in Apollo 15, landed near the foothills of the Lunar Apennines, and drove their 'moon-car' up to the edge of the great chasm known as the Hadley Rill; the scientific haul was far greater than that of any previous Apollo mission. Next, Astronauts Young and Duke, in Apollo 16, came down in the highlands of Descartes, and provided still more fascinating information. Their mission was particularly vital because it was the only Apollo scheduled for such an area; and it led to some surprises. The region contained much more breccia than had been expected, and this alone was enough to cause theoretical astronomers to revise at least some of their pre-conceived ideas.

Meanwhile, the Russians had successfully dispatched, and recovered, another unmanned lunar mission. The two programmes seemed, outwardly, to have little in common; but when President Nixon visited Moscow in 1972 he signed an important agreement with the Soviet leaders which, if implemented, will lead to much greater co-operation in space. The Americans are now planning their Skylab space-station, while it is reasonable to assume that the Russians have similar plans. We may now hope that in the foreseeable future a Soviet probe will be able to dock with a United States orbital station – or vice versâ. If so, then all humanity will benefit.

The Mars probes of 1971-72 have, in their way, been as triumphant as the Apollo missions. As they are described elsewhere in this *Yearbook*, there is no point in saying more about them here; but we must pause to mention the Pioneer vehicle which has been dispatched toward Jupiter, and which may be expected to by-pass the Giant Planet at the end of 1973. During its fly-by, Pioneer will approach within 90,000 miles of Jupiter, and will send back scientific information of all kinds. Theorists are particularly interested in the Jovian magnetic field, which is certainly very strong, and which is bound up with the enigmatical emissions at radio wavelengths.

After leaving the region of Jupiter, Pioneer will sweep onward and pass out of the Solar System altogether, so becoming Man's first messenger into interstellar space. Obviously, all track of it will soon be lost. Its makers have thoughtfully equipped it with a plaque intended to explain its origin to any alien civilization which might intercept it; but one has to admit that the chances of its ever being found are not very high!

So far as Jupiter is concerned, an investigation of very different kind has been made possible by the event of 13-14 May 1971. Jupiter occulted the star Beta Scorpii, and a team at the Cape Observatory in South Africa, led by Dr A. P. Fairall, found that the star showed regular brightenings and fadings just before and just after the actual occultations; this is attributed to effects in the Jovian atmosphere, which is presumably stratified – layers of relatively dark 'clouds' alternating with clearer layers. Equally interesting was the fact that Io, Jupiter's innermost large satellite, occulted Beta Scorpii C. Using these observations, Gordon E. Taylor of the Royal

Greenwich Observatory, Herstmonceux, has been able to show that the diameter of Io is 3659 kilometres. The possible error is only 5 kilometres, and so it seems that Io really is considerably larger than our Moon (diameter 3476 kilometres). However, Io is less dense than the Moon, and has a slightly lower escape velocity, so that no atmosphere there can be expected.

From time to time there have been revivals of interest in the possibility of a trans-Plutonian planet. In 1972 new calculations were made by J. L. Brady, of the Livermore Laboratory in California, indicating that the planet may be at twice the distance of Neptune, moving in a retrograde orbit in a period of over 500 years; the mass is estimated at three times that of Saturn. Brady's calculations were based not on the perturbations of the known outer planets, but upon the movements of Halley's Comet. He suggests that the planet has remained undetected because it has a high orbital inclination (120 degrees) and lies in Cassiopeia, well away from the ecliptic and well away from any areas studied by previous planet-hunters. If the magnitude is above 15, as he believes, the planet should be comparatively easy to locate; but it is fair to say that the calculations are speculative, at least in some respects, and that many theorists are sceptical about the idea of a large planet moving in a retrograde direction. However, searches are in progress – and if the planet exists in this area of the sky, no doubt it will be found in due course.

One important development in instrumental astronomy has been the progress with the great new Russian reflector, which should be operational very shortly, and which will deprive the Hale reflector at Palomar of its proud title of 'the world's largest'. In England, the famous 28-inch refractor formerly at Greenwich was transferred back to its old home; for some years it has been at Herstmonceux. It is hoped to bring the refractor back into full use before the end of 1973, and to use it for a certain amount of demonstration work as well as actual research.

Arguments about cosmology continue unabated. The evolutionary universe, the cyclic or oscillating universe, and some forms of the old steady-state theory continue to have enthusiastic supporters. One significant suggestion has been made by Dr D. S. de Young, of the Green Bank radio astronomy observatory in West Virginia. He has produced evidence that there is a considerable amount of cool gas between the galaxies which occur in clusters; and he believes that the average density of the gas is 15 times as great as it is in the spaces between separate clusters of galaxies. If confirmed, this result will lend support to theories which require the existence of a much greater quantity of matter than is visible in the galaxies themselves.

Quasars remain as enigmatical as ever, and it cannot honestly be said that much fundamental progress in solving their problems was made during the period between mid-1971 and mid-1972. It is not even certain whether they are immensely remote and luminous (as most astronomers believe) or whether they are comparatively close to our own Galaxy (as a few rebels still maintain). Pulsars, on the other hand, have been explained as neutron stars; the rapid variations are due to the rotation of the star, and the regular passage of the Earth through a 'beam' of radiation sent out. This is still nicknamed the lighthouse effect. However, the pulsar in the Crab Nebula, at a distance of roughly 6,000 light-years, remains the only one to have been identified with an optical object; and even if we are right about the nature of the pulsars, much research remains to be done with respect to them.

Eclipsing binary stars have been very much to the fore. It has been suggested, in particular, that the larger, infra-red component of the extraordinary system Epsilon Aurigæ may not be a very young star in the process of contraction, but an extremely old object which now consists of a very small, superdense stellar remnant which is the centre of a 'black hole' – from which nothing (not even light) can escape. Whether this is correct or not remains to be seen; it is difficult to visualize these 'black holes', otherwise termed collapsars, though they are theoretical possibilities. At Green Bank, C. M. Wade and R. M. Hjellming found that two famous eclipsing binaries, Algol and Beta Lyræ, were detectable at radio frequencies; previously the only optically normal stars known to be radio sources were Antares B and Cygnus X-1, each of which is a binary. It has been suggested that the radio emission comes from gas streaming across the gap between the two components of the binary.

Another important optical identification comes from the x-ray astronomers, in this case headed by Dr I. Shklovskii of the U.S.S.R. The so-called 'x-ray pulsar' Centaurus X-3 has been identified with the variable star LR Centauri. Shklovskii suggests that LR Centauri too is a binary, and that the x-ray source is the smaller but brighter member of the pair. There is a chance of yet another optical identification of an x-ray source, thanks to some ingenious research carried out by British teams led by K. A. Pounds and P. Willmore. Calculations had shown that the source would be occulted by the Moon twice in successive months, and so x-ray detectors were sent up in rockets at the critical moments. Each occultation gave a 'position line' along which the source must lie; and the actual position was given by the intersection of the two lines. As yet the final results of the experiment have not been given, but it seems that the source may be identified with what looks like a faint, normal star.

Of course the Crab Nebula is an x-ray source, as well as being a radio emitter. It is known to be the remnant of a supernova observed by Oriental astronomers in the year 1054. Recent work by Dr J. K. Alexander and his colleagues in Maryland has indicated that the Gum Nebula, in the southern hemisphere of the sky, is also a supernova remnant; they calculate that the outburst occurred about 11,000 years ago – or, to be more precise, it would have been seen from Earth 11,000 years ago. It is suggested that a search of the records of primitive societies in the southern hemisphere might possibly show that something unusual was visible around 9000 B.C.

Primitive man would not have understood the cause of a supernova. Yet even today there are people with strange ideas, and one episode of 1971 seems to take us back a good many centuries. A lunar eclipse was visible from Cambodia, and was popularly ascribed to a mythological monster named Reahou, which was trying to eat the Moon. The result was that soldiers of the Cambodian Army used their Western-made automatic rifles to fire round after round at the Moon, during which procedure they killed two onlookers and wounded fifty. Old beliefs die hard.

The Mundrabilla Meteorite

G. J. H. McCALL

Early in 1964, information was given to the author that there was a large iron meteorite somewhere out on the Nullarbor Plain, as its name implies a treeless waste of limestone gibbers mantled by thin grass and bush cover, and extending for some 900 miles between Western and South Australia. This information was given by a doctor, who had it from an amateur prospector: it was certainly secondhand and there was reason to suspect that it was thirdhand! The prospector appeared to have visited the area (though this has never been substantiated), but whether he had actually seen the mass he reported remains, to this day, in question. The actual finder was a rabbit trapper, one Harrison, now deceased; he was reported to have discovered the mass in the course of his everyday pursuits, and brought back two medium-sized pieces, found near to his camp.

Many such tales are heard at the Western Australian Museum, which services an area one-third the size of the United States, occupied by a bare million people. However, what lent veracity to the tale was the fact that a map was supplied, and the prospector named had brought a small iron meteorite in to the Government Chemical Laboratories at Perth. The map showed tracks leading off north from the Trans-Australian Railway line: mileages; the site of the main mass; a fettlers' camp; and one track was marked 'to Harrison's Camp'. The fettlers' camps are usually spaced every fifteen miles along the line, the longest and loneliest straight stretch of permanent way in the world, measuring nearly 300 miles without a curve. The map was deficient in that it did not specify which camp, and in that the mileages subsequently proved to be not quite accurate.

A preliminary sortie to the site was made by the author and W. R. O'Beirne. They journeyed 900 miles by road from Perth, and set to work traversing rough tracks across the limestone plain, to no avail. The back axle of the utility started to detach itself from the chassis, and a strategic withdrawal, 500 miles back to Kalgoorlie, ensued. This first sortie established that it was either one of two possible fettlers' camps and that, map or no map, success in the search was not likely to be achieved without an arduous programme. The search was likely to be hard and long – how long, fortunately, was not guessed!

Nevertheless, two days later the author and W. H. Cleverly returned once more, 500 miles to the site. They tried to locate Harrison's Camp, but again without avail. This time the search was terminated due to excessive tyre wear on the station wagon. They were very close at one time to the actual site, and so were the next two abortive searches. W. D. L. Ride searched the same area, only to be driven back by tyre failure, and, in 1965, D. C. Lowry with W. A. Crowle actually recovered three small irons. These are the small shed irons that are now known to surround the main masses, but how close Lowry and Crowle came to success cannot be ascertained, for these irons have been found up to twenty miles from the main masses, and possibly forty.

Small masses known as Premier Downs I, II, and III were recovered along the railway line in 1911 and 1914 (McCall & De Laeter, 1965, p. 48), and another similar mass known as Loongana Station was left by the prospector at the Government Chemical Laboratories (*ibid* p. 38). These are certainly outlying members of the enveloping shower of shed irons, surrounding the Mundrabilla main masses.

By mid-1965, the Western Australian Museum had information that suggested a large iron did lie out on the plain, about twenty miles north of the railway track, but it had the uneasy suspicion that the search was akin to that for the proverbial 'needle in the haystack'. Enthusiasm slackened, for the four trips to this remote area had used up funds, and some participants had been forced to undertake long walks to obtain new tyres for abandoned vehicles. All the author could do was delineate a four-mile square, and this was declared a ministerial reserve, by the Mines Dept., in case a meteorite should come to light within it.

Then chance took a hand! In March 1966, Bruce Wilson, a geologist, and A. M. Cooney, his assistant, were detailed by Geosurveys, an Adelaide Mineral Exploration Company, to examine this area on behalf of an oil company which suspected that certain circular patterns visible on air photos might represent oil traps (tectonic fold structures). This was not the case, as Wilson demonstrated; but this is what brought Wilson and Cooney to the Nullarbor. They had to traverse this featureless plain by Land-Rover, and were faced with a navigation problem. They had to line up the compass standing outside the vehicle, and then drive on the target, an apparently prominent bush on the skyline, which inevitably turned out to be exaggerated by the mirage on reaching it. This terrain is like an Atlantic swell, and one can lose oneself on foot within minutes of leaving the vehicle: continual swerves to avoid limestone gibbers likewise cause rapid loss of direction at the wheel unless the compass is used. One of the prominent bushes on the skyline turned out to be a large iron meteorite! Wilson and Cooney camped against it in a falling drizzle, strangely, for the Nullarbor Plain sees such rainfall but rarely, being one of the most arid areas of the Earth, with extreme heat in summer and bleak cold in winter.

The prospector had described a single large mass, partly obscured by spinifex grass and surrounded by some medium-sized irons and many small irons. Wilson and Cooney found that there was, in fact, another large mass some 200 yards to the south, and that the entire surrounding terrain was littered with small iron masses, each measuring an inch or two across. The description of the partial obscuration by spinifex grass was accurate, as was the general description of the site – ‘on the edge of a slight escarpment overlooking an area of rabbit bur-

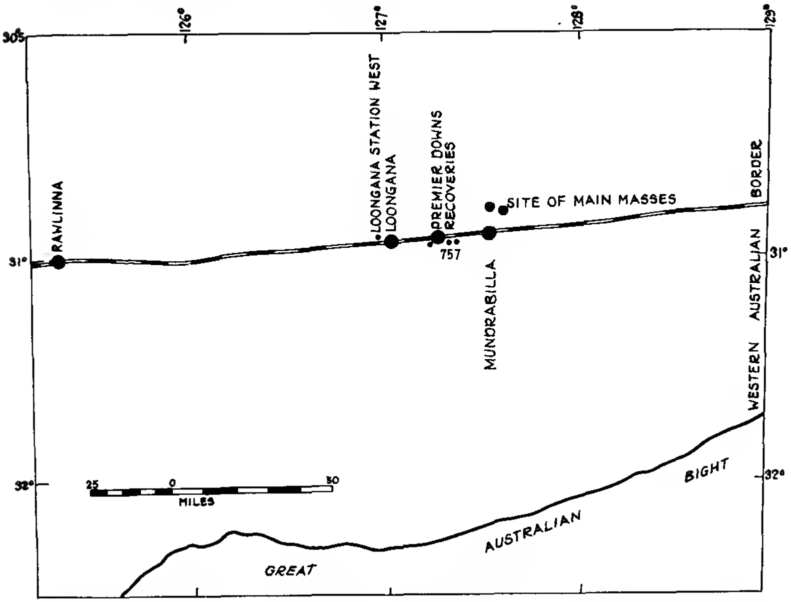

Fig. 1. Sketch map of the site of find of the main masses and shed irons.

rows (claypans)'. The suspicion arises, however, that the only person actually to see the site was Harrison, and all other descriptions were at second or third hand. This could explain the inaccuracy of the map. Though neatly drawn, it showed the key track leading northwards from the railway line some miles out of position: but for this, the site would have been reached by the first party! This turn off was the key to the whole search.

The fettlers' camp turned out to be named Mundrabilla, and this name was given to the two large masses and shed irons. To avoid confusion the names Premier Downs and Loongana Station were retained, though these small irons, outliers of the shed irons, are paired falls with Mundrabilla. In 1967, the well-known naturalist, W. H. Butler, brought in an iron from west of Loongana Station: this was named Loongana

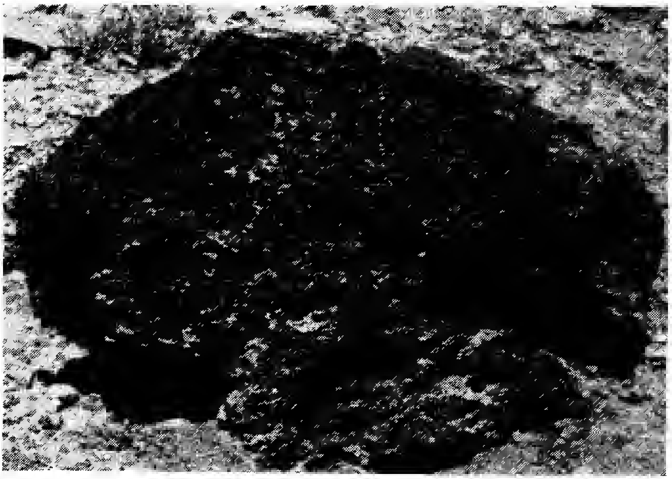

Fig. 2. A sample shed iron.

Station West and must also be paired with Mundrabilla, for it too is a shed iron. This iron was reportedly picked up some forty miles from the site of the main masses! The distribution of the shed irons is strange, but it is a very difficult matter for research, requiring an exhaustive programme and the setting up of a surveyed grid on a large area of the plain.

Two masses weighing 11 and 5 tons respectively were recovered from the Plain, and these are two halves of a larger single mass that entered the Earth's atmosphere, for they both show an identical shaped suture of separation, in the one case concave and in the other convex. The split occurred at some time during atmospheric entry prior to landing on the surface. The larger mass shows a similar undeveloped split, parallel to the surface of separation. The smaller, 5-ton mass somersaulted before landing and thus was found with the reverse side buried in the ground. The larger meteorite has the characteristics of an oriented mass, crudely resembling the familiar cone form of the space capsule and showing radial marks of ablation streaming of melted iron from the centre of the leading surface

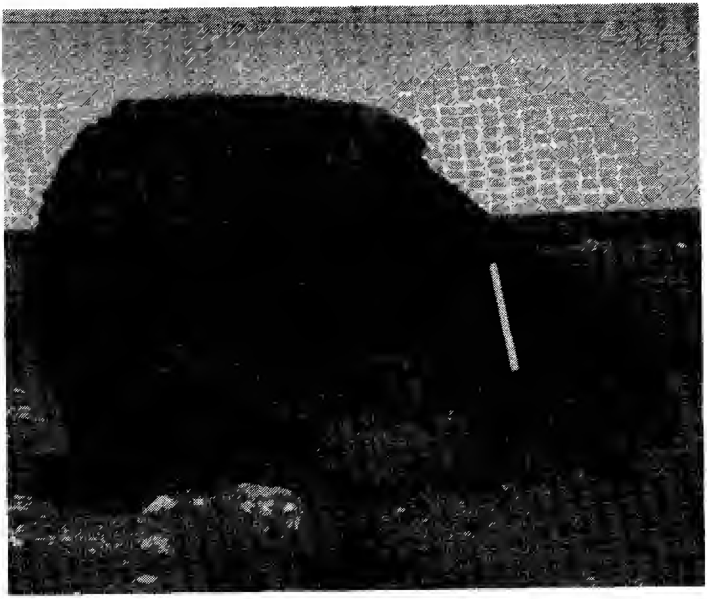

Fig. 3. The larger mass, M1, 11 tons, seen *in situ.* The spinifex grass has been cut away and the ground slightly excavated. Note the concave parting surface, with hackly protuberances, and the contrasting primary ablation surface, curved and striated. The mass drove in to the surface at a steeply oblique angle of descent, from the west (right). The shed irons probably separated from the hackly parting.

('stagnation point'), striations due to frictional dermal heating during atmospheric entry. After the split, the smaller mass tumbled in space due to instability, but prior to this the mass had not tumbled: probably the larger mass never tumbled, even after the split occurred, for the striated front of the cone drove into the limestone surface at a steeply oblique angle of approach from the west, and the mass remained in that position. There is some cracking of the limestone, but how much is simply due to normal weathering effects is difficult to estimate. The rock surface has suffered remarkably little deformation from the sudden impress of such a large mass of iron, and there is no sign of cratering beneath either mass.

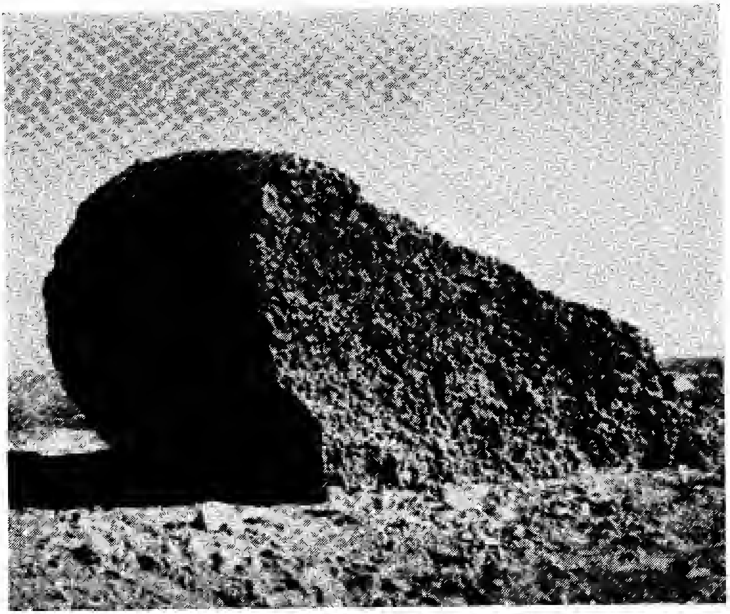

Fig. 4. The smaller M2 mass, 5 tons, seen *in situ*, showing the convex parting surface, complementary to that on the M1 mass (concave). The underlying pad of iron shale is well seen.
Both photographs reproduced in black and white from kodachromes by R. B. Wilson.

The small, shed irons are present by the hundred: an attempt to survey them was abandoned a few hundred yards from the main masses, for there appeared to be no end to them and no decrease in concentration. There can be no doubt that they were shed from the mass during ablation. No other large iron mass known is surrounded by such a satellite swarm of shed irons, all of inch scale and extending out from the large mass for at least twenty miles and probably more than forty. The small irons (quite distinct from the shale balls) surrounding Crater Mound at Canon Diablo, Arizona, and the small irons found 4 miles from the Wolf Creek Crater, Australia (McCall, 1968) may provide a limited analogy.

The two masses were recovered by the Main Roads Department of Western Australia using low-loaders and bulldozers, and were loaded on to rail trucks at the nearest site of a loading ramp, Rawlinna Station, some 150 miles to the west of the site. From there they journeyed to Kalgoorlie. Considerable problems were encountered en route with souvenir hunters armed with hacksaws, but damage thereby was not serious. At Kalgoorlie they parted company for ever: the largest mass, M1, journeyed to Perth. The Western Australian Museum has lately taken possession of a fine new building, and M1 is now on display there on a pedestal. It will eventually form the centrepiece of a remarkable meteorite display including the smaller Quairading, Haig, Youanmi, and Mount Edith irons; and the spectacular Bencubbin and Mount Padbury stony irons. It will be seen by generations of people, including the countless schoolchildren who flock to this excellent museum in the holidays and may perhaps fire more than one with an abiding interest in natural science!

The M2 mass eventually journeyed to Adelaide in South Australia: it will eventually be put on display in the Museum there, alongside the world's largest stony iron, the Huckitta pallasite, but meanwhile, has journeyed to Heidelberg, Germany, where Professor P. Ramdohr is to cut it. Months of slow cutting will, it is hoped, produce a number of large slices for research and display. The Western Australian Museum, because it paid the cost of recovery from the desert, is entitled to one of these slices, to enhance its display; the others will go to collections all over the world.

When the Museum agreed to recover the two large masses, they were thought to be octahedrites, of the most common type of iron meteorite. The main incentive was to secure these magnificent display specimens which otherwise would surely have been blasted to pieces by souvenir hunters, the fate of some valuable historic shipwrecks off the West Australian coast. This recovery became doubly important, however, when it was discovered that this was no ordinary meteorite. It is a most rare

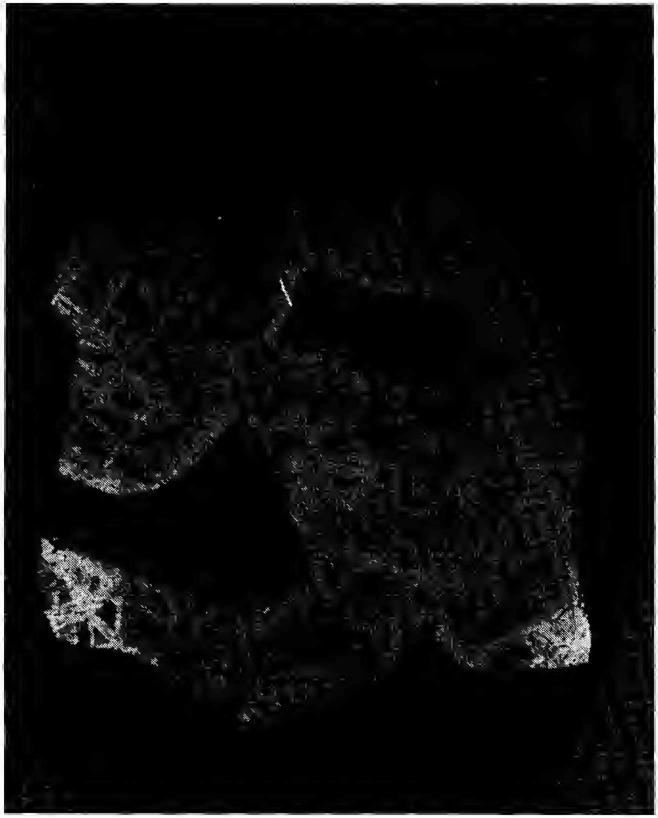

Fig. 5. The etch pattern showing on a polished, etched cut surface. The diverse orientation of small areas of Widmanstätten pattern is evident, together with areas of troilite and graphite (dark).

type known as a granular octahedrite, with silicate inclusions. Only three or four such meteorites are known, the most similar being one that fell in Soroti, Uganda. The mass consists of a proliferation of small areas of Widmanstätten pattern, tightly bonded together without intervening matrix or separated by areas of troilite and graphite (the former a sulphide of nickel iron, the end member of the pyrrhotite family). The silicate minerals olivine and pyroxene have been recorded by scientists using the eclectron probe at the B.H.P. laboratories in Australia, and Ramdohr and El Goresy have recognized (1971) that the unusually high troilite content is accompanied by unmixing products in the form of daubreelite ($FeCr_2S_4$), alabandite (MnS), and sphalerite (ZnS). The titanium oxide rutile is also present in a niobian form. The study of this rare meteorite is only beginning, and will continue for many years. Not only were two immense irons recovered, but a large quantity of material of a rare type added to the meteoritic store, the only material that Man can study from the interior of Solar System bodies, probably asteroids disintegrated by unknown agencies long ago.

The shedding of small irons appears to be related to the presence of the many variously oriented areas of nickel-iron alloy, which tended under ablation to come apart at the seams. Probably the troilite, a relatively low temperature melting mineral, melted out first and left promontories which later became completely detached from the mass. These promontories are, in fact, evident on the surfaces of the common suture between M1 and M2, the one concave and the other convex. One can suspect that the two masses parted company high in the atmosphere during ablation, but after the first, most intense heating: and the hackly nature of the new surfaces exposed allowed continued ablation and undermining of the promontories by melting of the troilite and some further metal.

Both masses are underlain by pads about ten inches thick of iron shale, due to the prolonged action of groundwater. Considering the almost total aridity of the area, this indicates a sojourn on the surface of the Nullarbor Plain of hundreds and probably thousands of years. So it is unlikely that the arrival of these masses was observed by Man. But what a spectacle it must have been! Consider that a single shower meteor can brighten up the night sky in a spectacular fashion, and the brilliant Leonid display is produced only by many minute specks of entrant extraterrestial matter. One small stony mass can produce a spectacular fireball, driving across the arch of the sky. Besides the two main masses, thousands of small shed irons must have descended at the same time, each producing its own fireball. If 'brighter than a thousand suns' exaggerates this spectacle, the sky must truly have been for some moments many times brighter than the sun at high noon, and the arch filled with innumerable descending brilliant fireballs.

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PART THREE

For Stellar Observers

Celestial Sights

PATRICK MOORE

The three previous articles in this *Yearbook* have dealt with astrophysical matters. So for the moment let us turn to something very much less technical, and put ourselves in the position of the interested star-gazer who is anxious to find some really spectacular stellar objects. There are plenty of them; the selection which follows is merely typical, but has been chosen from the viewpoint of someone who has nothing very elaborate in the way of equipment and who does not pretend to have any exhaustive knowledge of the sky.

Winter is a good time to begin, because we have Orion in full view – and the choice of objects is indeed wide. With a telescope, or a pair of binoculars, why not start with a glorious red star – Betelgeux (Fig. 1)? True, it looks like nothing more than a point of light; no telescope yet made will show a star as a true disk (if the star appears as a shimmering globe filling part of the field, you may be sure that there is something wrong with the focus). But the colour is striking, and is enhanced by the twinkling effects due to the atmosphere of the Earth. Not far away is another red star, Aldebaran in Taurus; it looks very similar to Betelgeux (though in fact its spectrum is of type K, not M), and extending from it, in a rough V-formation, are the stars of the Hyades cluster. Actually Aldebaran is not a member of the Hyades; it merely happens to lie about halfway between the cluster and ourselves.

As a contrast, swing your binoculars towards Sirius, much lower down and much brighter. As we have noted earlier, Sirius is white; but it seems to flash all the colours of the rainbow, because its light is coming to us via a thick layer of our

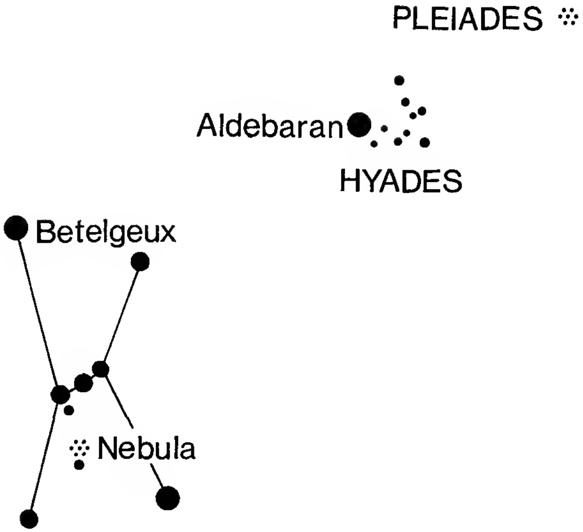

Fig. 1

atmosphere. Astronomers are not in the least fond of these gaudy colours, but nobody can deny that they look beautiful.

Still using binoculars, turn to the Pleiades, the magnificent open cluster in Taurus. Normal-sighted persons can see seven individual stars under good conditions; those people with keen sight can see more, but binoculars show that the cluster is extremely rich. Binoculars do, in fact, bring out the Pleiades to better advantage than a telescope, whose field is so much smaller that only part of the cluster will be visible at a time.

Next, what about the Great Nebula in Orion, M.42? It is visible to the naked eye as a hazy patch; binoculars reveal its filmy gas, but to see it really well a telescope is needed. Even with a low power on, say, a three-inch refractor the Nebula is a splendid sight, and you will be able to make out the multiple star Theta Orionis, nicknamed the Trapezium for obvious reasons. The Nebula is 1,500 light-years away, and contains many irregular variable stars which seem to be at an early stage in

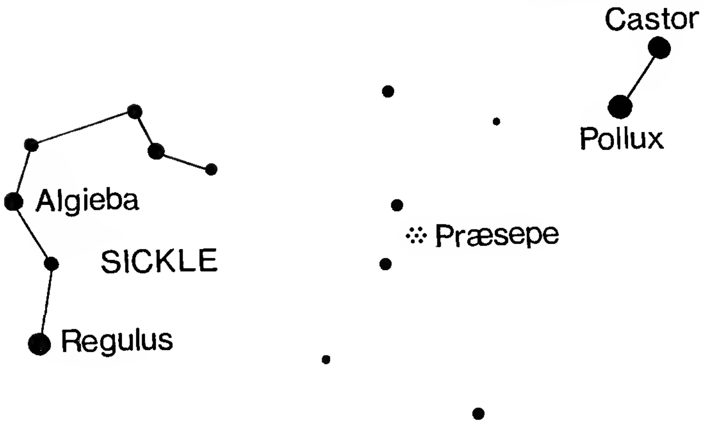

Fig. 2

their evolution, so that they are still contracting toward the Main Sequence.

Turning to spring skies, we have yet another spectacular cluster: Præsepe, in Cancer, the Crab (Fig. 2). It is No. 44 in Messier's catalogue, but has been known from ancient times – which is not in the least surprising, since it is easily visible to the naked eye on a moonless night. Aratus, who lived around 280 B.C. wrote that the invisibility of Præsepe on an apparently clear night was a sign of approaching bad weather. Look for it roughly half-way between Regulus in Leo and the two Twins, Castor and Pollux. It is flanked on either side by two relatively faint stars, Gamma and Delta Cancri.

Præsepe has been nicknamed 'the Beehive'. It is more open than the Pleiades, and for observing it binoculars are to be preferred to a telescope. It is rather over 500 light-years away, and seems to be older than the Pleiades, since it contains many red and yellow giants which have presumably evolved off the Main Sequence.

Leo itself is characterized by the curved line of stars making up the Sickle. Gamma Leonis (Algieba) is our next object for viewing; it is a binary star with a period of 407 years, so that over the course of a lifetime its aspect does not alter a great deal. The present separation is approximately 4 seconds of arc. Theoretically, a three-inch refractor will separate equal stars only two seconds apart, and so there should be no difficulty with Algieba; the magnitudes are 2·3 and 3·8, and the primary is a red giant of spectral type K. The real distance from us is 190 light-years. Algieba is one of the most rewarding of all double stars from the viewpoint of a small telescope; but do not forget Gamma Virginis (Arich), described on page 67. If you defer looking at Arich until the end of the century, your three-inch refractor will no longer be adequate to split it!

Before leaving spring skies, turn your binoculars toward Arcturus. Here again we have a K-type giant – light orange

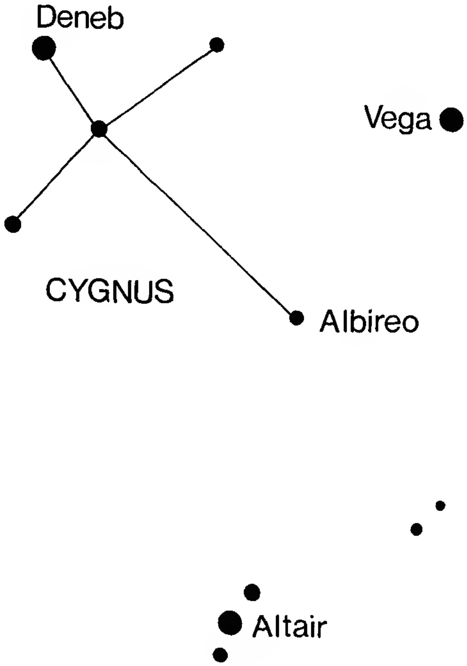

Fig. 3

rather than the duller orange-red of Betelgeux or Antares. Arcturus has the distinction of being the brightest star in the northern hemisphere of the sky, though it is only fractionally superior to Capella and Vega.

Summer evenings offer much of interest. To start with there is the Milky Way, extending across the sky in a band of radiance which is beautiful when seen from the countryside, though city lights obscure it completely. It is always enjoyable to take your binoculars and simply 'sweep round, ranging from Cygnus and Aquila through to the rich star-clouds of Sagittarius, near the horizon, which mark the direction of the centre of the Galaxy. In Cygnus, too, there is Albireo (officially, Beta Cygni), which is probably the loveliest of all double stars (Fig. 3). It is the faintest of the stars making up the X of Cygnus, and lies very roughly between Vega and Altair. Though it spoils the symmetry of the cross, it more than compensates in itself. The golden-yellow primary, of the third magnitude, has a fifth-magnitude companion which some people call bluish and others green. The colours are beautiful in their contrast; and since the separation is over 34 seconds of arc, Albireo can be split even with good binoculars – though a telescope naturally brings out the colours more vividly. In contrast, locate Alya or Theta Serpentis, which is a double of different kind (Fig. 4). The separation is 22 seconds of arc, so that it is extremely easy to split; each component is of magnitude 4·5, and each is white. Alya

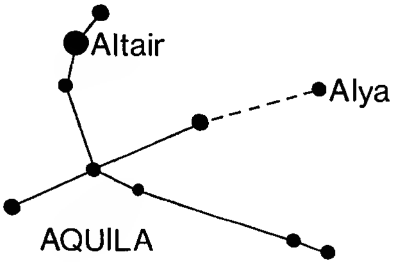

Fig. 4

can be identified without much trouble, since it lies almost in line with Theta, Eta, and Delta Aquilæ, below Altair.

In autumn we have the Pegasus-Andromeda region well displayed, and it is always worth looking at Messier 31, the Andromeda Galaxy (Fig. 5). Candidly, it is disappointing as a spectacle. Binoculars show it clearly, and keen-eyed people can see it with the naked eye; but the average-sized telescope will show it only as an elongated blur of light. On the other hand, it is sobering to reflect that in gazing at the Andromeda Galaxy you are looking back over two million years in time. It is permissible to wonder how many astronomers there are looking at our own Galaxy, and seeing it as a blur of light in *their* sky.

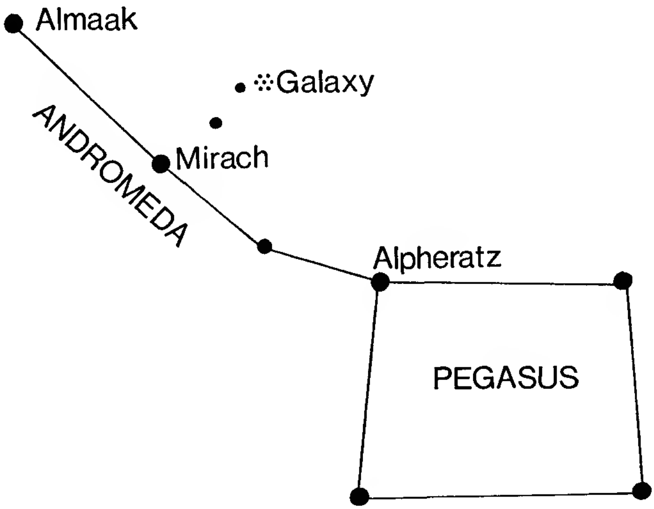

Fig. 5

Also in Andromeda is another excellent double, Gamma or Almaak. The magnitudes are two and five, the separation almost 10 seconds of arc, and the distance from us 260 light-years. The chief feature of Almaak is, again, contrasting colours; the primary is an orange K-type giant, while the companion is blue.

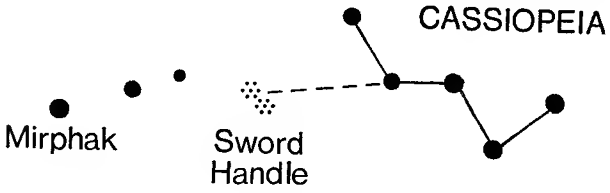

Fig. 6

Adjoining Andromeda is the W of Cassiopeia, one of the most familiar features of the northern sky. Also bordering Andromeda is Perseus, which contains several bright stars, including the second-magnitude Mirphak and the celebrated eclipsing binary Algol. In Perseus, near the border of Cassiopeia, may be seen a misty patch which is, in fact, made up of two star-clusters, nicknamed the Sword-Handle (not to be confused with the Sword of Orion). For some unexplained reason the clusters were not included in Messier's catalogue, and are generally known as H.VI.33 and 34; H stands for the great observer William Herschel, who discovered so many clusters and nebulæ during his career.

Binoculars are adequate to show the clusters well, but the best effects are obtained with a wide field and a low magnification on a telescope. The richness is striking; the whole field seems full of stars. Figure 6 shows how to locate the Sword-Handle, which is dimly visible with the naked eye.

These notes do not pretend to be anything but fragmentary, but at least they may help to stress, yet again, that there is plenty to see in the stellar sky even with equipment which is inexpensive and limited in range.

Some Interesting Telescopic Variable Stars

	R.A.		Dec.			*Period,*	
Star	*h*	*m*	°	′	*Mag. range*	*days*	*Remarks*
R Andromedæ	0	22	+38	18	6·1–14·9	409	
W Andromedæ	2	14	+44	4	6·7–14·5	397	
R Aquilæ	19	4	+ 8	9	5·7–12·0	300	
R Arietis	2	13	+24	50	7·5–13·7	189	
R Aurigæ	5	13	+53	32	6·7–13·7	459	
R Boötis	14	35	+26	57	6·7–12·8	223	
R Cassiopeiæ	23	56	+51	6	5·5–13·0	431	
T Cassiopeiæ	0	20	+55	31	7·3–12·4	445	
T Cephei	21	9	+68	17	5·4–11·0	390	
Omicron Ceti	2	17	− 3	12	2·0–10·1	331	Mira.
R Coronæ Borealis	15	46	+28	18	5·8–14·8	–	Irregular.
W Coronæ Borealis	16	36	+37	55	7·8–14·3	238	
R Cygni	19	35	+50	5	6·5–14·2	426	
U Cygni	20	18	+47	44	6·7–11·4	465	
W Cygni	21	34	+45	9	5·0–7·6	131	
SS Cygni	21	41	+43	21	8·2–12·1	–	Irregular.
Chi Cygni	19	49	+32	47	3·3–14·2	407	Near Eta.
R Draconis	16	32	+66	52	6·9–13·0	246	
R Geminorum	7	4	+22	47	6·0–14·0	370	
U Geminorum	7	52	+22	8	8·8–14·4	–	Irregular.
S Herculis	16	50	+15	2	7·0–13·8	307	
U Herculis	16	23	+19	0	7·0–13·4	406	
R Hydræ	13	27	−23	1	4·0–10·0	386	
R Leonis	9	45	+11	40	5·4–10·5	313	Near 18, 19.
X Leonis	9	48	+12	7	12·0–15·1	–	Irregular (U Gem type).
R Leporis	4	57	−14	53	5·9–10·5	432	'Crimson star.'
R Lyncis	6	57	+55	24	7·2–14·0	379	
W Lyræ	18	13	+36	39	7·9–13·0	196	
HR Delphini	20	40	+18	58	3·6–?	–	Nova, 1967.
Nova Vulpeculæ	19	45	+27	2	4·8–?	–	Nova, 1968.
U Orionis	5	53	+20	10	5·3–12·6	372	
R Pegasi	23	4	+10	16	7·1–13·8	378	
S Persei	2	19	+58	22	7·9–11·1	810	Semi-regular.
R Scuti	18	45	− 5	46	5·0–8·4	144	
R Serpentis	15	48	+15	17	5·7–14·4	357	
SU Tauri	5	46	+19	3	9·2–16·0	–	Irregular (R CrB type).
R Ursæ Majoris	10	41	+69	2	6·7–13·4	302	
S Ursæ Majoris	12	42	+61	22	7·4–12·3	226	
T Ursæ Majoris	12	34	+59	46	6·6–13·4	257	
S Virginis	13	30	− 6	56	6·3–13·2	380	
R Vulpeculæ	21	2	+23	38	8·1–12·6	137	

Some Interesting Double Stars

The pairs listed below are well-known objects, and all the primaries are easily visible with the naked eye, so that right ascensions and declinations are not given. Most can be seen with a 3-inch refractor, and all with a 4-inch under good conditions, while quite a number can be separated with smaller telescopes, and a few (such as Alpha Capricorni) with the naked eye. Yet other pairs, such as Mizar-Alcor in Ursa Major and Theta Tauri in the Hyades, are regarded as too wide to to be regarded as bona-fide doubles!

Name	*Magnitudes*	*Separation,″*	*Position angle, deg.*	*Remarks*
Gamma Andromedæ	3·0, 5·0		060	Yellow, blue. B is again double (0″·4) but needs a larger telescope.
Zeta Aquarii	4·4, 4·6	2·6	291	Becoming more difficult.
Gamma Arietis	4·2, 4·4	8	000	Very easy.
Theta Aurigæ	2·7, 7·2	3	330	Stiff test for 3 in. OG.
Delta Boötis	3·2, 7·4	105	079	Fixed.
Epsilon Boötis	3·0, 6·3	2·8	340	Yellow, blue. Fine pair.
Kappa Boötis	5·1, 7·2	13	237	Easy.
Zeta Cancri	5·6, 6·1	5·6	082	
Iota Cancri	4·4, 6·5	31	307	Easy. Yellow, blue.
Alpha Canum Venat.	3·2, 5·7	20	228	Yellowish, bluish. Easy.
Alpha Capricorni	3·2, 4·2	376	291	Naked-eye pair. Alpha again double.
Eta Cassiopeiæ	3·7, 7·4	11	298	Creamy, bluish. Easy.
Beta Cephei	3·3, 8·0	14	250	
Delta Cephei	var, 7·5	41	192	Very easy.
Xi Cephei	4·7, 6·5	6	270	Reasonably easy.
Gamma Ceti	3·7, 6·2	3	300	Not too easy.
Zeta Coronæ Borealis	4·0, 4·9	6·3	304	
Delta Corvi	3·0, 8·5	24	212	
Beta Cygni	3·0, 5·3	35	055	Yellow, green. Glorious.
61 Cygni	5·3, 5·9	25	150	
Gamma Delphini	4·0, 5·0	10	265	Yellow, greenish. Easy.
Nu Draconis	4·6, 4·6	62	312	Naked-eye pair.
Alpha Geminorum	2·0, 2·8	2	151	Castor. Becoming easier.
Delta Geminorum	3·2, 8·2	6·5	120	
Alpha Herculis	var, 6·1	4·5	110	Red, green.
Delta Herculis	3·0, 7·5	11	208	Optical double.
Zeta Herculis	3·0, 6·5	1·4	300	Fine, rapid binary.
Gamma Leonis	2·6, 3·8	4·3	121	Binary; period 400 years.
Alpha Lyræ	0·0, 10·5	60	180	Vega. Optical; B faint.
Epsilon Lyræ	4·6, 6·3	3	005	Quadruple. Both pairs separable in 3 in. OG
	4·9, 5·2	2·3	111	
Zeta Lyræ	4·2, 5·5	44	150	Fixed. Easy double.
Beta Orionis	0·1, 6·7	9·5	205	Rigel. Can be split with 3 in.
Iota Orionis	3·2, 7·3	11	140	

Name	*Magnitudes*	*Separation,"*	*Position angle, deg.*	*Remarks*
Theta Orionis	6·0, 7·0 7·5, 8·0			The famous Trapezium in M.42
Sigma Orionis	4·0, 7·0 7·5, 10·0	11·1 12·9	236 085	Quadruple. D is rather faint in small apertures.
Zeta Orionis	1·9, 5·0	3	160	
Eta Persei	4·0, 8·5	8·5	300	Yellow, bluish.
Alpha Piscium	4·3, 5·3	1·9	291	
Alpha Scorpii	0·9, 6·8	3	275	Antares, Red. green.
Nu Scorpii	4·2, 6·5	42	336	
Theta Serpentis	4·1, 4·1	23	103	Very easy.
Alpha Tauri	0·8, 11·2	130	032	Aldebaran. Wide, but B is very faint in small telescopes.
Zeta Ursæ Majoris	2·3, 4·2	14·5	150	Mizar. Very easy. Naked eye pair with Alcor.
Alpha Ursæ Minoris	2·0, 9·0	18·3	217	Polaris. Can be seen with 3 in.
Gamma Virginis	3·6, 3·7	4·8	305	Binary; period 180 yrs. Closing.
Theta Virginis	4·0, 9·0	7	340	Not too easy.

Some Interesting Clusters and Nebulæ

Object	R.A.		Dec.		*Remarks*
	h	*m*	°	′	
M.31 Andromedæ	00	40·7	+41	05	Great Galaxy, visible to naked eye.
H.VIII 78 Cassiopeiæ	00	41·3	+61	36	Fine cluster, between Gamma and Kappa Cassiopeiæ.
M.33 Trianguli	01	31·8	+30	28	Spiral. Difficult with small apertures.
H.VI 33–4 Persei	02	18·3	+56	59	Double cluster; Sword-handle.
M.1 Tauri	05	32·3	+22	00	Crab Nebula, near Zeta Tauri.
M.42 Orionis	05	33·4	−05	24	Great Nebula. Contains the famous Trapezium, Theta Orionis.
M.35 Geminorum	06	06·5	+24	21	Open cluster near Eta Geminorum.
H.VII 2 Monocerotis	06	30·7	+04	53	Open cluster, just visible to naked eye.
M.41 Canis Majoris	06	45·5	−20	42	Open cluster, just visible to naked eye.
M.44 Cancri	08	38	+20	07	Præsepe. Open cluster near Delta Cancri. Visible to naked eye.
M.97 Ursæ Majoris	11	12·6	+55	13	Owl Nebula, diameter 3′. Planetary.
M.3 Canum Venaticorum	13	40·6	+28	34	Bright globular.
M.80 Scorpionis	16	14·9	−22	53	Globular, between Antares and Beta Scorpionis.
M.4 Scorpionis	16	21·5	−26	26	Open cluster close to Antares.
M.13 Herculis	16	40	+36	31	Globular. Just visible to naked eye.
M.92 Herculis	17	16·1	+43	11	Globular. Between Iota and Eta Herculis.
M.7 Scorpionis	17	51·6	−34	48	Fine open cluster. Very low in England.
M.23 Sagittarii	17	54·8	−19	01	Open cluster nearly 50′ in diameter.
H.VI 37 Draconis	17	58·6	+66	38	Bright Planetary.
M.8 Sagittarii	18	01·4	−24	23	Lagoon Nebula. Gaseous. Just visible with naked eye.
NGC 6572 Ophiuchi	18	10·9	+06	50	Bright planetary, between Beta Ophiuchi and Zeta Aquilæ.
M.17 Sagittarii	18	18·8	−16	12	Omega Nebula. Gaseous. Large and bright.
M.11 Scuti	18	49·0	−06	19	Wild Duck. Bright open cluster.
M.57 Lyræ	18	52·6	+32	59	Ring Nebula. Brightest of planetaries.
M.27 Vulpeculæ	19	58·1	+22	37	Dumb-bell Nebula, near Gamma Sagittæ.
H.IV 1 Aquarii	21	02·1	−11	31	Bright planetary near Nu Aquarii.
M.15 Pegasi	21	28·3	+12	01	Bright globular, near Epsilon Pegasi.
M.39 Cygni	21	31·0	+48	17	Open cluster between Deneb and Alpha Lacertæ. Well seen with low powers.

PART FOUR

Miscellaneous

Some Recent Books

Astronomy, by Robert H. Baker and Laurence W. Fredrik (9th edition, Van Nostrand, New York). A new edition of this standard textbook, fully revised and updated.

Mathematical Astronomy for Amateurs, by E. A. Beet (David & Charles, Newton Abbot). An excellent introduction, particularly suitable for first-year students.

Discovering the Universe, by C. A. Ronan (Basic Books, New York). A general but comprehensive account of the development of our ideas about the universe.

The Astronomy of Birr Castle, by Patrick Moore. The story of the largest telescope of the last century, built by one man – the Earl of Rosse.

Norton's Star Atlas and Telescopic Handbook, by A. P. Norton (Gall & Inglis, Edinburgh). A new issue of this classic book, widely regarded as the best of all outline star atlases. The entire text has been revised and modified by a team of astronomers under the general editorship of Robert Inglis.

Our Contributors

G. A. Hole, Director of the Instruments and Observing Methods Section of the British Astronomical Association, is one of Britain's most celebrated optical workers. Equipment manufactured by George Hole & Son is to be found in many major observatories throughout the world.

H. G. Miles, B.E.M., B.Sc., Lecturer in Mathematics at the Lanchester College of Technology in Coventry, is Director of the Artificial Satellites Section of the British Astronomical Association. His other astronomical interests include studies of fireballs and meteors. He is the author of many scientific papers, and has contributed to many past *Yearbooks*.

G. E. Satterthwaite was formerly a professional astronomer at the Royal Greenwich Observatory, but is now engaged in scientific publishing. His special interests lie in positional astronomy and in planetary studies. He is Director of the Saturn Section of the British Astronomical Association.

Henry Brinton has his private observatory at Selsey, in Sussex; the main instrument is a 12-inch reflector. His chief astronomical interest is in photography.

Iain Nicolson, B.Sc., is Lecturer in Astronomy at the Hatfield Polytechnic. He is a graduate of St Andrews University, and is the author of many papers and several books.

D. A. Allen, M.Sc., graduated from Cambridge and became a specialist in the field of infra-red astronomy, in which he has undertaken fundamental research. During part of 1972 he was in the United States, carrying out his researches at Palomar Observatory.

DR SIMON MITTON, M.A., M.INST.P., lives in Cambridge, where he carried out research on radio galaxies until 1971. Since then he has concentrated mainly upon scientific writing, and is the U.K. editor of *Astrophysical Letters*.

DR G. J. H. MCCALL is British, but has for some years been living in Australia. He is a specialist in the study of volcanic structures, and has carried out much original research – notably in connection with the vulcanoids in Africa. He is also particularly interested in meteorites and was deeply concerned with the great Western Australian collection at Perth. Dr McCall has also written extensively on lunar geology.

Astronomical Societies in Great Britain

The advantages of joining an astronomical society are obvious enough. Full information about national and local Societies was given in the 1966 *Yearbook;* a condensed list, suitably brought up to date, is given below.

Name	*Secretarial Address*	*Yearly Subscription* §=members under 18, or 'juniors'	*Meeting Time and Place*
British Astronomical Association	Burlington House, Piccadilly, London, W.1. (J. L. White)	£3·25 (§£2·50)	Burlington House, Piccadilly Last Wed. each month (Oct-June)
Junior Astronomical Society	58 Vaughan Gardens, Ilford, Essex	£1	Alliance Hall, Palmer St., WC1 Last Saturday Jan., April, July, Oct. 2.30 p.m.
Aberdeen and District Astronomical Society	14 Ahbotshall Gardens, Cults, Aberdeen (W. P. Cooper)		Robert-Gordon's Institute of Technology, St Andrew Street, Aberdeen
Altrincham and District Astronomical Society	10 Delamere Road, Gatley, Cheadle, Cheshire (Colin Henshaw)	25p	Park Road Library, Timperley 1st Friday of each month 7.30 p.m.
Aylesbury Astronomical Society	9 Elm Close, Butler's Cross, Aylesbury (N. Neale)	£1	As arranged
Birmingham Astronomical Society	17 Hannafore Road, Edgbaston, (W. E. Marsh)	£1 (§25p)	Birmingham and Midland Institute Monthly
Bridgwater Astronomical Society	The Technical College, Broadway, Bridgwater, Somerset	50p	A.T.C. H.Q., Rope Walk, Bridgwater, 3rd Thursday in each month
Brighton Astronomical Society	6 Old Shoreham Road, Hove 4, Sussex (Brigadier V. M. Papworth)		
Bristol Astronomical Society	34 Butterfield Close, Bristol BS10 5AZ (G. H. Woodman)	£2·50 (§52½p)	Royal Fort (Rm G44) Bristol University last Friday each month, Sept.-May
Caithness and Dounreay Astronomical Society	Room 31, Ormlie Lodge, Thurso, Scotland (Miss M. J. A. Clark)	£1	Fortnightly
Cambrian Astronomical Society	43 Heol Chappell, Whitchurch, Cardiff (G. Stokes)	75p (§37p)	Every 3rd week, 7.30 38 Park Place, Cardiff
Cambridge Astronomical Society	5 Haggis Gap, Fulbourn (S. R. Whistler)	£1·05 (§37½p)	7 Brooklands Avenue, Cambridge 2nd Mon. each month Oct.-July

Name	*Secretarial Address*	*Yearly Subscription* §=members under 18, or 'juniors'	*Meeting Time and Place*
Chelmsford and District Astronomical Society	65 Longstomps Avenue, Chelmsford, Essex (J. N. Trompeter)		Civic Centre, Chelmsford Friday Nights
Chester Astronomical Society	37 Alwyn Gardens, Upton, Chester (A. Kemp)	£1 (§50p)	St Andrews House, Newgate St., Chester Monthly
Chester Society of Natural Science, Literature and Art	26 Guy Lane, Waverton, nr Chester (Mrs N. Hoskyns)	—	Grosvenor Museum, Chester Fortnightly
Chesterfield Astronomical Society	Hilltop Cottage. Gallery Lane, Holymoorside, Chesterfield (Mrs R. C. Naylor)	£1 (§50p)	Barnett Observatory, Newbold Each Friday
Clackmannanshire Astronomical Society	9 Deer Park, Sauchie, Alloa (J. Cluckie)	£1	St Mary's School, Alloa Monthly, 3rd Friday Sept.-May
Cleethorpes Astronomical Society	95 Sandringham Road, Cleethorpes, Lincolnshire (W. S. Cobley)	£1 (§50p)	Dolphin Hotel, Cleethorpes Monthly
Crawley Astronomical Society	Crawley College of Further Education, Sussex (F. D. Cooper)	37p	Crawley College of Further Education Monthly
Crayford Manor House Astronomical Society	Manor House Centre, Crayford, Kent (R. H. Chambers)	None	Manor House Centre, Crayford Monthly during term-time
Croydon Astronomical Society	64 Cromwell Rd., Caterham, Surrey (N. E. Fisher)	— 5p entrance fee to meetings	The Old Whitgiftian Sports Club, Lime Meadow Ave., Sanderstead, Surrey Alternate Fridays 7.45 p.m.
Dundee Astronomical Society	4 Finlaggan Place, Dundee, Scotland (D. Gavine)	50p (§25p)	Mill's Observatory, Dundee Fortnightly in the winter
Eastbourne Astronomical Society	80 Ringwood Road, Eastbourne, Sussex (W. O. Tutt)	£1·05 (§52½p)	As arranged Monthly
East Lancashire Astronomical Society	95 Accrington Road, Blackburn (L. Willan)	£1 (§37½p)	Longridge Observatory Preston
Astronomical Society of Edinhurgh	126 W. Saville Terrace, Edinhurgh 9, Scotland (N. G. Matthew)	£1	Calton Hill Observatory, Edinburgh Monthly
Ewell Astronomical Society	11 Elmwood Drive, Ewell, Surrey (L. J. Bentley)	£1 (§50p)	Ewell County Technical College, Reigate Road, Ewell, Surrey 1st Friday of each month
Fellowship of Junior Astronomers, Edinhurgh	58 Ogilvie Terrace, Edinburgh 11, Scotland (Miss Edith McLean)	37½p	Calton Hill Observatory, Edinburgh 2nd Sat. each month, Sept.-June
Fylde Astronomical Society	28 Belvedere Rd, Thornton, Lancs (—)	£1 (§50p)	Stanley Hall, Rossendale Ave. South 1st Wed. each month
Astronomical Society of Glasgow	164 Mugdock Road, Milngavie, Glasgow, Scotland (N. M. Orr)	50p	Roy. Coll. Science and Tech., Glasgow 3rd Thur. each month, Sept.-April

Name	*Secretarial Address*	*Yearly Subscription* §=members under 18, or 'juniors'	*Meeting Time and Place*
Great Yarmouth Astronomical Society	38 Cobholm Road, Cobholm, Great Yarmouth, Norfolk (M. Poxon)	(To be announced)	(To be announced)
Herschel Society	35 Kendal Drive, Slough (C. Wise)	—	(To be announced)
Isle of Wight Astronomical Society	1 Hilltop Cottages, High Street, Freshwater, Isle of Wight (J. W. Feakins)	£1 (§50p)	Unitarian Church Hall, Newport, Isle of Wight Monthly
Leeds Astronomical Society	Maths. Dept., The University, Leeds 2 (B. L. Meek)	50p (§25p)	Leeds University Six annually
Leicester Astronomical Society	26 Falmouth Rd., Evington, Leicester (Mrs L. Withey)	£1·05 (37p)	Leicester Museum and Art Gallery Monthly
Lincoln Astronomical Society	344 Brant Road, Lincoln (P. Hammerton)	£1 (§25p)	Lincoln YMCA Hall 1st Tue. each month
Liverpool Astronomical Society	Simms Cross School Hse., Mitton Road, Widnes (D. Bradburne)	£1·50 (§75p)	City Museum, Liverpool Monthly
Loughton Astronomical Society	Aldersbrook House, Romford Road, Manor Park, E12 5LN (D. E. Brede)	£1·50 (§£1)	Loughton Hall, Rectory Lane, Loughton, Essex Thursdays, 8 p.m.
Luton Astronomical Society	20 Bloomfield Avenue, Luton (S. J. Anderson)	£1	Last Friday each month
Maidenhead Astronomy Group	129 Fane Way, Maidenhead, Berkshire (S. A. H. Roper)	50p (§12½p)	Maidenhead Grammar School Once every 3 weeks
Manchester Astronomical Society	Cragside, Cliff Avenue, Summerseat, Bury (Alan Whittaker)	£1 (§50p)	Godlee Observatory, Manchester 1 Weekly
Mansfield and District Astronomical Society	14 Bonnington Crescent, Sherwood Estate, Nottingham (G. W. Shepherd)	50p (§25p)	Monks Precision Engineering Co., Mansfield Rd., Sutton-in-Ashfield Last Monday of each calendar month
Newcastle-on-Tyne Astronomical Society	30 Kew Gardens, Whitley Bay, Northumberland (G. E. Manville)	£1	Botany Lecture Theatre, Newcastle University Monthly, Sept.-April
Newtonian Observatory Astronomical Society	62 Northcott Road, Worthing, Sussex (Miss P. E. Randle)	£1·20	Adult Education Centre, Union Place, Worthing 1st Wed. each month except Aug. 7.30 p.m.
North Dorset Astronomical Society	The Pharmacy, Stalbridge, Dorset (J. E. M. Coward)	—	Charterhay, Stourton, Caundle, Dorset 2nd Wed. each month
Norwich Astronomical Society	The Manse, Back Lane, Wymondham, Norwich	£1 (§50p)	The Observatory, Daniels Rd., Norwich 1st Tues. each month Sept.-May
Nottingham Astronomical Society	18 Naseby Close, Heathfield, Nottingham (C. Swift)	£1·25p	Monthly

Name	*Secretarial Address*	*Yearly Subscription* §=members under 18, or 'juniors'	*Meeting Time and Place*
Orwell Astronomical Society	59 Grimston Lane, St. Martin, Ipswich (—)	£1 (§50p)	Orwell Park School Nacton, Ipswich (as arranged)
Oxshott Astronomical Group	Norman Cottage, Pond Piece, Sheath Lane, Oxshott, Surrey (E. H. Noon)	50p	Oxshott Village Centre 1st Wed. each month Sept.-May
Paisley Astronomical Society	14 Cheviot Avenue, Barrhead, Glasgow (Mrs J. Holms)	£1 (§50p)	Coats Observatory, 49 Oakshaw Street, Paisley Monthly
Peterborough Astronomical Society	24 Cissbury Ring Werrington, Peterborough (E. Pitchford)	£1·25 (§25p)	Peterborough Technical College 2nd Tues., 3rd Thur. each month
Plymouth Astronomical Society	1 Valletort Cotts, Millbridge, Plymouth (G. S. Pearce)		Plymouth College of Technology, Tavistock Road, Plymouth Monthly
Portsmouth Astronomical Group	52 Denbigh Drive, Fareham, Hampshire (S. W. Hackman)	£3	The Group Observatory
Portsmouth Astronomical Society	91 Sutherland Road, Southsea (P. R. Seiden)	£1·50	Monday Fortnightly
Preston and District Astronomical Society	35 Bispham Road, Carleton, Poulton-le-Fylde, Lancs (C. Lynch)	£1 (§25p)	Chamber of Commerce, 49a Fishergate, Preston 3rd Mon. each month Sept.-May
Salford Astronomical Society	44 Pevensey Road, Salford 6 (A. Taylor)	£1 (§50p)	The Observatory, 3rd Wed. each month
Salisbury Plain Astronomical Society	St George's Cottage, Orcheston, Salisbury, Wilts. (R. J. D. Nias)	50p (§25p)	St George's Rectory, Orcheston Quarterly
Slough Astronomical Society	The Elms, Odds Farm, Green Common Lane, Wooburn Common, High Wycombe, Bucks (E. Shilton)	£1	Monthly
South Downs Astronomical Society	6 Queensfield East, West Meads, Bognor Regis	£2 (§£1)	Last Friday in each month
Southampton Astronomical Society	13 Luccombe Place, Shirley, Southampton (F. G. H. Cunningham)	£1·60 (§80p)	Ploygon Hotel, Southampton 2nd Thur. each month Sept.-May also observing sessions
Southport Astronomical Society	4 Warren Green, Freshfield, Lancs. (H. Bloch)	75p	As arranged Monthly
South Shields Astronomical Society	Marine and Technical College, St George's Ave., South Shields, Co. Durham (H. Haysham)	£1 (37½p)	Marine and Technical College Each Thursday, 7.30 p.m.
South West Herts Astronomical Society	32 Riverford Close, Harpenden, Herts. (G. J. B. Phillips)	£1·50 (§75p)	Royal Masonic School for Girls, Rickmansworth Last Fri. each month Sept.-May

Name	*Secretarial Address*	*Yearly Subscription* §=members under 18, or 'juniors'	*Meeting Time and Place*
Stoke-on-Trent Astronomical Society	Sundale, Dunnocksfold Road, Alsager, Stoke (M. Pace)	75p	Cartwright House, Broad Street, Hanley Monthly
Swansea Astronomical Society	77 Craiglwyd Road, Cockett, Swansea (R. E. Roberts)	£1	As arranged
Thanet Amateur Astronomical Society	85 Crescent Road, Ramsgate (P. F. Jordan)	25p	Hilderstone House, Broadstairs, Kent Monthly
Torbay Astronomical Society	4 Heath Rise, Brixham, Devon (Miss A. Longman)	75p (§25p)	Quay Tor Hotel, Scarborough Road, Torquay Monthly
Waltham Forest and District Junior Astronomy Club	24 Fulbourne Road, Walthamstow, London E17 (B. Crawford)	50p	24 Fulbourne Road, Walthamstow, London E17 Fortnightly (Mondays
Warrington Astronomical Society	2 Dale Avenue, Appleton, Warrington (B. P. Rees)	£1	Central Library, Museum Street, Warrington, Lancs Monthly, Sept.-May
Warwickshire Astronomical Society	20 Humber Road, Coventry, Warwickshire (R. D. Wood)	£4	20 Humber Road, Coventry Each Tuesday
Wolverhampton Astronomical Society	Garwick, 8 Holme Mill, Fordhouses, Wolverhampton (M. Astley)	£1	38 Tettenhall Road, Wolverhampton Alternate Mon., Sept.-April
Wessex Astronomical Group	St Catherine's Court, D4, 35 Christchurch Road, Bournemouth (Mrs H. Bagainy)	—	Ashley Cross Girls School, Lower Parkstone, Poole, Dorset 1st Tues. each month (except Aug.) 7.30 p.m.
West of London Astronomical Society	5 Blakesley Avenue, Ealing, W5 2DN (P. Macdonald)	40p	Monthly, alternately at Ruislip and North Harrow 2nd Monday of the month (except August)
Wyvern Astronomical Society	2 Howcroft, Churchdown, Gloucester (A. F. Edwards)	75p (§25p)	Clubhouse, Churcham Last Friday of each month except Aug.
Zenith Astronomical Society	4 Neptune House, Trafalgar Gardens, Burnley (A. Harvey)	£1 (§50p)	54 Cromwell Street, Burnley Monthly

It is possible that this list of local societies may not be quite complete. If any have been omitted, the secretaries concerned are invited to write to the Editor (c/o Messrs Sidgwick & Jackson (Publishers), Ltd, 1 Tavistock Chambers, Bloomsbury Way, London WC1), so that the relevant notes may be included in the 1974 *Yearbook*.

Astronomical Societies in the U.S.A.

The societies listed here are all open to the public. Most of them hold regular meetings once or twice monthly. Details of each society's programme can be obtained from the official whose name and address are given here.

†Member organization of the Astronomical League.
‡Member organization of the Western Amateur Astronomers.
° Society has junior section.
|| Independent junior society.

ALABAMA

BIRMINGHAM: Birmingham Astronomy Club, D. Hall, 512 Birch St., Trussville. GL 4–3117†
HUNTSVILLE: Rocket City Astronomical Assn., G. A. Ferrell, Jr., 621 Franklin St. JE 4 4809†

ARIZONA

PHOENIX: Phoenix Observatory Assn., T. Ballard, 1851 N. 37th St. BR 5–3018‡

ARKANSAS

LITTLEROCK: Arkansas Amateur Astronomy Club, W. Franke, 511 Louisiana St. MO 3–1681†

CALIFORNIA

BURBANK: Burbank Astronomical Society, D. Rhoades, 1474 N. Evergreen St. TH 8–5880
ESCONDIDO: Palomar Amateur Astronomers, M. A. Sloan, 2418 Alexander Dr. SH 5–6144‡
FRESNO: Central Valley Astronomers, G. Reavis, 626 W. Lamona. AM 4–9771‡
LONG BEACH: Excelsior Telescope Club, B. Sproul, 130 5th St.†‡
LOS ANGELES: Los Angeles Astronomical Society, Inc., Mrs. C. Vicars, 1954 Talmadge. NO 4–1650‡°
LOS GATOS: Los Gatos Amateur Astronomers, L. Anthenien, 1725 Hicks Ave., San Jose (25). 269–5561
NORTH HOLLYWOOD: San Fernando Valley Astronomical Society, J. W. Harvey, 11640 Weddington St. PO 3–3011
OAKLAND: Eastbay Astronomical Society, Mrs. S. Burke, 1528 E. 31st. KE 6–0691‡
PALO ALTO: Peninsula Astronomical Society, Miss A. Alksne, 4115 Amaranta Ave. DA 2–4406‡
PASADENA: Stony Ridge Observatory, Inc., E. Sloman, 1100 Armada Dr. SY 6–4731‡
POMONA: Junior Astronomical Society of Pomona Valley, 1540 Arroyo Ave. 629–0352‡||
REDLANDS: Valley Amateur Astronomers, R. Bell, Jr., 937 N. Palm Ave., Ontario. YU 4–0331‡
RIVERSIDE: Riverside Astronomical Society, H. E. Kaiser, 4868 Hedrick Ave., Arlington OV 9–2574
SACRAMENTO: Sacramento Valley Astronomical Society, Mrs. E. F. Williams, 3733 West Way (21). IV 7–3779‡
SAN DIEGO: CRA Youth Astronomy Club, D. Weisbrod, 4315 Hermosa Way (3). CY 5–4607||
San Diego Amateur Astronomers, Miss L. Franklin, 1985 Alameda Terrace (3). CY 8–5178
San Diego Lunar Society, T. Smith, 9654 Candy Lane, La Mesa. HO 3–5290

SAN FRANCISCO: San Francisco Amateur Astronomers, E. Taylor, 1626 Pacheco St. SE 1–4916‡°

SAN JOSE: San Jose Amateur Astronomers, W. Krumm, 10628 Larry Way, Cupertino‡

SAN MATEO: San Mateo Astronomical Society, R. Johnston, 806 Fiesta Dr. FI 5–7783°

SANTA BARBARA: Santa Barbara Star Cluster, Capt. C. Adair, 607 Miramonte Dr. WO 2–1717‡

STOCKTON: Stockton Astronomical Society, T. Pullum, 2076 W. Inman St. (4). HO 4–0704‡

WALNUT CREEK: Mount Diablo Astronomical Society, G. P. Fritzke, 961 Country Lane. YE 5–7086‡°

WHITTIER: Whittier Amateur Astronomers, Inc., R. K. Angel, 702 E. Walnut St. SY 9–7056‡

YREKA: Siskiyou County Astronomical Society, Mrs. A. James, W. Jackson St°

COLORADO

BOULDER: Boulder Astronomical Society, H. H. Howe, 2419 Pennsylvania Ave. HI 3–1051†

COLORADO SPRINGS: Colorado Springs Astronomical Society, M. Williams, 1306 E. Columbia. ME 3–9286†

DENVER: Denver Astronomical Society, R. A. Spencer, 4430 Gladiola St., Golden. CR 9–4682†‡°

PUEBLO: Pueblo Astronomical Society, N. Onstott, 2421 Second Ave. LI 3–3348†‡°

CONNECTICUT

GREENWICH: Scanners' Club Astronomical Society, G. Shea, 102 Milbank Ave. TO 9–4474

HARTFORD: Central Connecticut Amateur Astronomers, C. Hammond, 17 Greystone Rd., W. Hartford. JA 3–8813†

NEW HAVEN: Astronomical Society of New Haven, Inc., S. J. LeRoy, Northrop Rd., Woodbridge. FU 7–8683†

NEW LONDON: Thames Amateur Astronomical Society, R. Tumicki, 106 Canterbury Tpk., Norwich†

STAMFORD: Fairfield County Astronomical Society, N. B. Mickelson, 1 Gary Rd. DA 2–1300†°

DELAWARE

WILMINGTON: Delaware Astronomical Society, E. J. Volcheck, Jr., 325 Taft Ave. (5)†°

DISTRICT OF COLUMBIA

WASHINGTON: Maret Astronomers Club, P. Moretti, 3435 Yuma St. N.W. (8)‖

National Capital Astronomers, Mrs. J. Stolarik, 7805 Canyon Dr. N.E. (27)†°

Washington Junior Astronomers, C. Hanback, 2152 F St. N.W. (7). 338–1452‖

FLORIDA

BRADENTON: Gulf Coast Astronomical Society, D. L. Schrader, 4530 14th St. W. 745–1185

DAYTONA BEACH: Daytona Beach Star Gazers, W. T. Thomas, 105 N. Halifax. CL 2–8049

ELGIN AIR FORCE BASE: Choctaw Astronomical Society, Col. M. Marston, 710 Osceola Circle†

FORT MYERS: Fort Myers Amateur Astronomers Assn., G. Lucas, 5116 Via San Pablo. WE 6–1804†

JACKSONVILLE: Jacksonville Astronomy Club, Inc., E. L. Rowland, Jr. 345 E. Forsyth St. EL 4–6815

KEY WEST: Key West Astronomy Club, Mrs. C. Lott, Box 284†

LAKELAND: Central Florida Astronomical Society, C. Sammons, 1810 Fredericksburg Ave. MU 2–3223†

MIAMI: Miami Astronomical Assn., C. Silverman, 629 S.W. 11th St. FR 9–5202

Southern Cross Astronomical Society, A. P. Smith, Jr., 1601 S.W. 10th St. FR 4–7145†

ORLANDO: Orlando Amateur Astronomy Club, Dr. T. E. Gordon, Jr., 1410 N. Westmoreland Dr. GA 2–8226

ST. PETERSBURG: St. Petersburg Astronomy Club, Mrs. R. Angell, 233 5th Ave. N. 79–0544†

TAMPA: Tampa Amateur Astronomical Society, E. Z. Randall, 407 W. Chelsea St. (3). 33–6391

GEORGIA

ATLANTA: Atlantic Astronomy Club, W. H. Close, 225 Forkner Dr., Decatur. DR 3–3945†°

MACON: Macon Amateur Astronomers Club, G. Wood, Riverside Dr. SH 5–6486

HAWAII

HONOLULU: Hawaiian Astronomical Society, G. W. Bunton, B. P. Bishop Museum (17). 85951‡

IDAHO

BOISE: Boise Valley Astronomical Assn., S. Piepgrass, 3330 Wagon Wheel Rd. 344–5203†

TWIN FALLS: Southern Idaho Amateur Astronomers, N. Herrett, 1220 Kimberly Rd. RE 3–0868

ILLINOIS

CHICAGO: Aldebaran Astronomical Assn., M. Porcelino, 4020 N. Marmosa. PE 6–1736

Chicago Astronomical Society, E. Ganek, 10921 Linn Ct.

Chicago Junior Astronomical Society, R. Eramia, 4722 N. Hermitage. AR 1–2961†||

Illini Astro-Observers, W. Wedmore, 79A S. Westmore Ave., Lombard, MA 7–1871

GALESBURG: Galesburg Amateur Astronomers, H. L. Horein, 1246 N. Morton Ave. DI 2–0873†

MACON: Macon Astronomical Society, Rev. A. J. Tamulis, 375 Miller St. RO 4–3795†

MOLINE: Popular Astronomy Club, Dr. H. Nelson, 2439 17th Ave., Rock Island†

PEORIA: Peoria Astronomical Society, R. Van Zandt, 1100 N. Parkside Dr. 4–5621†

SPRINGFIELD: Sangamon Astronomical Society, B. Schmitt, Jr., 308 E. Farley. LA 3–2088

INDIANA

EVANSVILLE: Evansville Astronomical Society, Dr. R. T. Dufford, 512 S. Weinbach Ave. (14). GR 6–7856†

FORT WAYNE: Fort Wayne Astronomical Society, Inc., W. E. Herriman, R. R. 10, Southcrest Trailor Court. 27K, Poe°

INDIANAPOLIS: Indiana Astronomical Society, Inc., W. Wilkins, 6124 Dewey Ave. (19). FL 7–5946†°

MADISON: Madison Junior Astronomy Society, T. A. Winkel, 607 N. East St. 387–R†||

SOUTH BEND: St. Joseph Valley Astronomical Society, Miss I. DeBruycker, 1023 S. Union St. Mishawaka. BL 5–0560

IOWA

BURLINGTON: Burlington Astronomy Club, J. Polson, 2214 Barrett St. PL 4–6064

DES MOINES: Des Moines Div., Great Plains Astronomical Society, R. T. Morehead, R. R. 1, Beaver Ave. (10)

DUBUQUE: Dubuque Astronomical Society, H. W. Klauer, 1795 Adair St.

KANSAS

TOPEKA: Topeka Astronomical Society, J. Simpson, 4218 W. 30th St. CR 2–7130

WICHITA: Wichita Astronomical Society, S. Whitehead, 425 N. Lorraine (14). MU 2–6642†

KENTUCKY

BOWLING GREEN: Jaggers Astronomical Society, Mrs. J. C. Cottrell, 1530 State St. VI 3–8164†

LEXINGTON: Bluegrass Astronomical Society, J. Hayden, 336 Colony Blvd. 6–7657†°

LOUISVILLE: Louisville Astronomical Society, Mrs. T. E. Field, 1554 Cardinal Dr. (13). GL 8–3885°

Louisville Junior Astronomical Society, J. Kielkopf, 4708 St. Rita Dr. (19) WO 9–6861†||

LOUISIANA

LAKE CHARLES: Lake Charles Amateur Astronomers Club, C. Fronczek, 2511 German Rd., Westlake. HE 6–1797

NEW ORLEANS: New Orleans Amateur Astronomers Assn., W. E. Wulf, 2107 Annunciation St. JA 5–0706†

SHREVEPORT: Shreveport Astronomical Society, D. Schwartzenburg, 208 E. Rutherford. 868–1802||

MAINE

PORTLAND: Astronomical Society of Maine, Mrs. O. H. Mayberry, Millbrook Rd., Scarboro†

MARYLAND

BALTIMORE: Baltimore Astronomical Society, Maryland Academy of Sciences, Pratt Libr. Bldg., 400 Cathedral St. (1). MU.5–2370†

SILVER SPRING: Naval Ordnance Laboratory Astronomy Club, I. Schroader, Applied Physics Lab., Johns Hopkins Univ., 8621 Georgia Ave. JU 9–7100

MASSACHUSETTS

CAMBRIDGE: Amateur Telescope Makers of Boston, G. Wood, Jr., Giles Rd., S. Lincoln. 259–8797†

Bond Astronomical Club, R. C. Smith, 519 Morrissey Blvd., N. Quincy (71). GR 2–1938†

NEW BEDFORD: Amateur Astronomy Club of New Bedford, M. Correia, 22 Ashley St. WY 2–6305

SALEM: North Shore Astronomical Society, F. Welch, 31 Fairview Rd.†

SPRINGFIELD: Springfield Stars Club, J. E. Welch, 107 Lower Beverly Hill, W. Springfield. RE 4–9179†°

WESTHARWICH: Cape Cod Astronomy Club, C. Perisho, HA 465†

WORCESTER: Aldrich Astronomical Society, A. Nieuwenhoff, 3 Crestview Dr., Holden†

MICHIGAN

BATTLE CREEK: Battle Creek Amateur Astronomy Club, Mrs. W. V. Eichenlau, 47 Everett Ave. WO 2–3059†

DEARBORN: Dearborn Astronomical Club, Dr. L. Van Becelaere, 21355 Knudsen Dr., Grosse Ile.

DETROIT: Detroit Astronomical Society, Inc., B. L. Reber, 22131 Ulster (19). KE 7–4197†°

FLINT: Flint Astronomy Club, Mrs. C. Adams, 610 Grand Blanc Rd., Grand Blanc†

Flint Junior Astronomy Club, D. G. Blondin, 3505 Holly Ave. (6)‖

GRAND RAPIDS: Grand Rapids Amateur Astronomical Assn., R. Larson, 3706 Lawn St. N.W. 453–9301†°

KALAMAZOO: Kalamazoo Astronomy Club, Mrs. V. Shellman, 3811 Allandale Ave. FI 4–8295‡

LANSING: Lansing Amateur Astronomers, R. D. Bonner, 725 N. Magnolia Ave. IV 4–9834°

MARQUETTE: Marquette Astronomical Society, F. Rydholm, 119 W. Arch. CA 5–0167†

PONTIAC: Pontiac-Northwest Detroit Astronomers Assn., Mrs. M. Klarick, 17390 Wiltshire Lathrup Village. EL 7–0364†°

MINNESOTA

MINNEAPOLIS: Minneapolis Astronomy Club, Mrs. M. B. Haarstick, Science Mus., Pub. Libr. FE 8–0781†

Minneapolis Junior Astronomy Club, Mrs. M. B. Haarstick, Science Mus., Pub. Libr. ‖

ST. PAUL: Astronomers' Club of St. Paul, R. Melarion, 896 E. Jenks Ave. (6)†‖

MISSISSIPPI

LAUREL: Laurel Sky Club, Mrs. R. Wates, 13 Country Club Dr. 87068†

RAYMOND: Amateur Astronomers Club, F. Stephenson, Hinds Junior College 857–5805

MISSOURI

KANSAS CITY: Astronomy Club of Kansas City, Mrs. L. Kinsey, 1522 Brush Creek (10). WA 3–3410†

T. JOSEPH: International Amateur Astronomical Society, J. Milnar, 1817 Dalton St. AD 4–3424°

Midland Empire Astronomical Society, Mrs. E. Davis, 206–B S. 14th AD 4–0048†°

ST. LOUIS: Astronomers' Club of St. Louis, K. Hornberger, 1111 Avant Dr. (37). †‖

St. Louis Astronomical Society, J. Ross, 5790 Kingsbury Pl. (12). PA 6–0458†°

MONTANA

MISSOULA: Western Montana Astronomical Society, E. K. Badgley, Jr., 314 Mary Ave.

NEBRASKA

LINCOLN: Prairie Astro Club, J. Williams, 1315 S. 40th St. 488–2112

OMAHA: Omaha Astronomy Society, Inc., Mrs. E. Heinz, 5124 S. 20th St. (7). 731–1237†

NEVADA

RENO: Astronomical Society of Nevada, A. A. Garroway, 2040 Meadow View Lane. FA 3–0696‡

NEW HAMPSHIRE

KEENE: Keene Amateur Astronomers, Inc., P. N. Atwood, 173 Island St. †•

MANCHESTER: Manchester Astronomical Society, R. E. Durette, 8 Keene St., Bedford. NA 5–8167

NASHUA: Merrimack Valley Astronomical Society, P.O. Box 108, Reeds Ferry

NEW JERSEY

CALDWELL: West Essex Astronomical Society, R. M. Greenley, 412 Bloomsfield Ave. CA 6–6751

CLIFTON: Clifton Astronomical Society, J. Ziemba, 144 Piaget Ave. 772–1857†‖

FAIR HAVEN: S*T*A*R Astronomy Society, Inc., Society for Telescopy, Astronomy, and Radio, S.F.K. Priebe Corresponding Member, 41 Woodland Drive.

FORT MONMOUTH: Society of Telescopy, Astronomy and Radio, W. E. Harris, 298 Broad St. Eatontown. LI 2–0476

JERSEY CITY: Gregory Mem. Obs. of Paul Revere Boys Club, E. F. Jones, 339 Wayne St. (2)†‖

MOORESTOWN: Moorestown Amateur Astronomy Assn., G. Bond, 15 E. Camden Ave.‖

NEWARK: Newark Museum Astronomy Club, A. Frielink, Jr., 43 Washington St. MI 2–0011

PRINCETON: Amateur Astronomers Assn. of Princeton, E. Abelson, 300 Western Way. WA 4–9143

RUTHERFORD: Astronomical Society of Rutherford, Mrs. A. Cox, 478 Riverside Terr. WE 9–0453

TEANECK: Bergen County Astronomical Society, W. DeForge, Jr., 424 W. Anderson St., Hackensack. HU 9–3436†

UPPER MONTCLAIR: Montclair Telescope Club, R. Boegehold, 280 N. Mountain Ave. PI 6–0495

NEW MEXICO

ALBUQUERQUE: Albuquerque Astronomers, D. Judd, 320 13th St. N.W. CH 3–4955†

LAS CRUCES: Astronomical Society of Las Cruces, J. E. Durrenberger, Box 625. JA 6–2968†‡

NEW YORK

ALBANY: Albany Astronomical Assn., V. D. Manti, 36 Marsdale St. IV 2–7279‡°

BINGHAMTON: Astronomical Society of Broome County, P. Budine, 102 Trafford Rd. RA 2–7335

Roberson Science Assn., D. E. Masters, 161 Trafford Rd. RA 2–5055°

BUFFALO: Buffalo Astronomical Assn., L. Reinagel, 194 Westgate Rd., Kenmore (17). DE 3455†

Buffalo Junior Astronomical Society, M. Fink, 69 Pine Ridge Rd., Cheektowaga. TX 6–6271‖

CHAPPAQUA: Northern Westchester Astronomical Society, W. P. Smith, 130 Castle Rd, CE 8–3853

CORNING: Corning Astronomy Club, Mrs. E. Johnston, 106 Jennings St. 2–5142

FARMINGDALE: Long Island Students of Astronomy, W. Huebner, 69 Duane St. CH 9–8793

HUNTINGTON: Long Island Observers' Assn., J. Littmann, 51 Cliftwood Dr. HA 3–6316†

LEVITTOWN: Levittown Amateur Astronomers, S. Page, 22 Corncrib Lane

MASSAPEQUA: Astronomical Society of Long Island, Mrs. B. Witham, 84 Bay Dr. PY 8–0029

MELVILLE: Airborne Recreation Assn. Astronomy Club, A. Dresner, 224 Grange St., Franklin Square. IV 9–3098

NEW YORK: Amateur Astronomers Assn., Inc., R. E. Priest, 223 W. 79th St. (24). TR 4–9064†

Astronomical Society of New York City, T. W. Hamilton, 235 Seaman Ave. (34). LO 9–1712.

Junior Astronomy Club, New York Univ., 100 Washington Sq. E. (3)†‖

PATCHOGUE: Long Island Astronomical Society, R. Franklin, 174 Jayne St.

POUGHKEEPSIE: IBM Astronomical Society, H. Dee, Dept. 067, Bldge. 905. GL 4–1000

ROCHESTER: Astronomy Section, Academy of Science, C. O. Field, 213 Hartsdale Rd. (22) HO 7–7925†

SCHENECTADY: Bishop Gibbons Astronomy Club, Br. A. E. Newman, F.S.C.H., 2602 Albany St. EX 3–3131†‖

Schenectady Astronomy Club, R. Cooper, 22 Wagner Ave. (4)†

SYRACUSE: Syracuse Astronomical Society, C. D. Fuller, 130 Falls Blvd., Chittenango†

TROY: Rensselaer Astrophysical Society, Dr. R. Fleischer, Rensselaer Polytechnic Inst.†

UTICA: Utica Amateur Astronomers, F. Staudaher, 8 Tanglewood Rd., New Hartford. RA 4–6211†°

WATERTOWN: Northern New York Amateur Astronomers, L. Beaumont, Box 133, Evans Mills

YONKERS: Yonkers Astronomy Club, B. Simon, 9 Valley View Dr. YL 8–7681†

NORTH CAROLINA

CHAPEL HILL: Chapel Hill Astronomy Club, B. Melvin, Rte. 2. 9–9447
GREENSBORO: Greensboro Astronomy Club, J. P. Patton, Jr., 3504 Tanglewood Dr. CY 9–0194†

NORTH DAKOTA

GRAND FORKS: Red River Astronomy Club, Miss M. Barlow, 704 Cottonwood St. 2–2473

OHIO

AKRON: Astronomy Club of Akron, Mrs. V. Spencer, 1034 Cordova Ave. UN 4–9197
CINCINNATI: Cincinnati Astronomical Assn., G. A. Lineback, 2933 Cortelyou Pl. (13). JE 1442
Cincinnati Astronomical Society, Miss M. Stone, 5767 Cheviot Rd. (39). WE 1–0954
CLEVELAND: Cleveland Astronomical Society, Dr. J. J. Nassau, Warner and Swasey Obs. Taylor Rd., E. Cleveland (12). GL 1–5625
COLUMBUS: Columbus Astronomical Society, Mrs. J. Gann, 420 N. Cassady Rd. (9) CL 2–8421†
DAYTON: Miami Valley Astronomical Society, F. Sutter, 5038 Far Hills Ave. (59). AX 3–1827†°
DOYLESTOWN: Chippewa Astronomical Society, R. C. Booth, R. D. 1, Box 26A, 658–2542
LIMA: Lima Astronomy Club, Mrs. V. Schneider, 706 St. Andrews Blvd.†
MARIETTA: Marietta Astronomical Society, Miss L. E. Cisler, Cisler Terrace. FR 3–0231°
MASSILLON: Massillon Astronomy Club, W. J. Crawford, 1545 First St. N.E.
STEUBENVILLE: Ohio Valley Amateur Astronomers, F. Donaldson, Box 270. AT 2–5821
TOLEDO: Star and Sky Group of Toledo Naturalists, Dr. M. Bell, 2257 Upton Ave. 472–7827
Toledo Astronomical Society, C. Schalow, 706 Culley Dr., Holland. UN 5–5392
WARREN: Mahoning Valley Astronomical Society, Mrs. C. R. Prather, 1363 Drexel Ave. N.W. EX 3–3483
YOUNGSTOWN: Youngstown Astronomy Club, D. Recklies, 806 E. Florida Ave. ST 2–0853

OKLAHOMA

OKLAHOMA CITY: Astronomy Club of Oklahoma City, E. Brett, 2624 N.W. 34th St.†
TULSA: Asteroids, M. Madden, 2737 E. Newton Pl. WE 9–7550.
Astronomy Club of Tulsa, Mrs. G. Rose, 4697 S. Columbia Ave. (5). RI 7–6729†

OREGON

PORTLAND: Amateur Telescope Makers and Observers, Miss M. Kobs, 5215 N.E. 30th Ave. (11). AT 2–8843†‡
Portland Astronomical Society, Mrs. M. Krutsinger, 6525 N.E. Davis (16). AL 4–1491†
SALEM: Salem Astronomical Society, Mrs. B. W. Christensen, 1430 Marshall Dr. EM 4–6626†°

PENNSYLVANIA

ALLENTOWN: Lehigh Valley Amateur Astronomical Soc., D. Temperley, 2033 Troxell St. 868–7949°
HARRISBURG: Astronomical Society of Harrisburg, H. Bitner, 700 Glen St. KI 5–5463†
PHILADELPHIA: Amateur Astronomers of Franklin Inst., E. F. Bailey, Franklin Inst. (34). LO 4–3600†
Brahe Astronomical Society, S. Karpchuk, Jr., 3304 Oakmont Ave. (36)||
Rittenhouse Astronomical Society, D. D. Davis, Franklin Inst. (34). LO 4–3600†
PITTSBURGH: Amateur Astronomers Assn. of Pittsburgh, F. M. Garland, 210 Park Pl. (37). 364–3211†°
Junior Amateur Astronomers Assn. of Pittsburgh, A. Zappa, 314 S. Evaline St. 361–1691†||
SCRANTON: Lackawanna Astronomical Society, Miss J. Woelkers, 311 Willow St. DI 2–8593
STATE COLLEGE: Nittany Valley Amateur Astronomers, Mrs. P. B. Lovett, 626 W. Nittany Ave. AD 7–7019
VILLANOVA: Villanova Astronomical Society, Rev. E. F. Jenkins, O.S.A., Villanova Univ. LA 5–4600†

WAYNESBORO: Astronomical Society of Waynesboro, J. Snider, 1021 S. Coldbrook Ave., Chambersburg. CO 4–4838†°

RHODE ISLAND

PROVIDENCE: Skyscrapers, Inc., Miss U. Clarke, 61 Adams Point Rd., Barrington. CH 5–7828

SOUTH CAROLINA

COLUMBIA: Columbia Astronomical Society, Science Museum, 1519 Senate St. AL 3–6975

SOUTH DAKOTA

RAPID CITY: Rapid City Astronomical Society, Dr. R. Heckman, F. D. School of Mines and Technology. FI 3–1600°

SIOUX FALLS: Sioux Falls Amateur Astronomy Club, D. Ness, 2305 Carter Pl. ED 2–5893

TENNESSEE

CHATTANOOGA: Barnard Astronomical Society, R. G. Duncan, 217 Hillside Dr. (11)†

GREENEVILLE: Greeneville Astronomical Society, D. Rockhill, R.F.D. 8 College View. ME 8–6875

KNOXVILLE: Knoxville Astronomical Assn., D. L. Bower, 2110 Fairmont Blvd. 2–1798°

MEMPHIS: Memphis Astronomical Society, G. P. Turner, 3713 Wilshire Rd. (11)†

NASHVILLE: Barnard Astronomical Society, Miss P. H. Hudgens, Dyer Obs., Vanderbilt Univ. CY 7–8811

PORTLAND: Portland Astronomical Society, R. O. Biggs, Box 42, 3781

TEXAS

ABILENE: Abilene Astronomical Society, R. B. Edmundson, 1849 N. 8th St. OR 4–5932°

AUSTIN: Capital City Astronomers, E. Stewart, 1319 Madison. HO 5–1312.

DALLAS: Texas Astronomical Society, E. M. Brewer, 5218 Morningside Ave. (6). TA 6–3894†°

EL PASO: Orion Society of El Paso, R. B. Minton, Jr., 7755 Ranchland Dr. LY 8–0596

FORT WORTH: Fort Worth Astronomical Society, R. M. Camp, Jr., 2826 Gordon†

Fort Worth Junior Astronomical Society, D. H. Gallagher, Children's Mus., 1501 Montgomery. PE 2–1461†||

HOUSTON: Houston Amateur Astronomy Club, W. W. Myers, 7424 Tipps St. (23). WA 6–5947

LAREDO: Laredo Astronomy Club, S. Freidin, 2220 Davis Ave.

LUBBOCK: South Plains Astronomy Club, Dr. F. C. Trusell, 4706 45th St. SW 5–3903†°

MIDLAND: Midland Amateur Astronomical Society, J. Ladd, 1606 N. Big Spring. MU 2–3229†

SAN ANGELO: San Angelo Amateur Astronomy Assn., L. Ingham, 130 W. 30th St. †°

SAN ANTONIO: San Antonio Astronomy Club, R. Garren, 109 Thoraine Blvd.

WICHITA FALLS: North Texas Astronomical Society, J. M. Marshall, Box 300. 692–1220. ext. 316

UTAH

SALT LAKE CITY: Astronomical Society of Utah, J. W. Geertsen, 4461 S. 9th East St. (17). AM 6–4602

VERMONT

BURLINGTON: Burlington Astronomy Club, J. Freeman, 100 De Forest Rd. UN 3–3800||

SPRINGFIELD: Springfield Telescope Makers, C. R. Ranney, 3 Hillcrest Rd. 5–2436†

VIRGINIA

LYNCHBURG: Blue Ridge Amateur Astronomers, J. E. Ardery, 2900 Rivermont Ave. VI 6–3584†

NORFOLK: Norfolk Astronomical Society, D. Berent, 1109 Brunswick Ave. (8). MA 2–8069†°

RICHMOND: Richmond Assn. of Junior Astronomers, Dr. E. Hoff, 117 Gaymont Rd. (26). AT 8–3368||

Richmond Astronomical Society, F. S. Clark, 6205 Clover Lane (28)†

WASHINGTON

SEATTLE: Seattle Amateur Astronomical Society, Inc., Miss D. Reilly, 4220 N.E. LA 2–5427†°

SPOKANE: Amateur Telescope Makers of Spokane, O. Heart, Rte. 1, Box 291, Hayden Lake Idaho†
TACOMA: Tacoma Amateur Astronomers, C. Stevens, 2207 S. 41st (9)†

WEST VIRGINIA

CHARLESTON: Carbide Astronomy Club, W. Casto, 333 Parkview Dr., St. Albans†
WHEELING: Oglebay Inst. Astronomical Assn., S. Brooks, Oglebay Inst., Speidel Obs. CH 3–6855

WISCONSIN

BELOIT: Beloit Astronomical Society, Dr. K. E. Patterson, 1023 McKinley Ave. EM 2–2242†
KENOSHA: Kenosha Amateur Astronomers, R. Henkel, 7625 18th Ave. OL 2–5225†
MADISON: Madison Astronomical Society, G. B. Harris, 1938 Sheridan St. CN 9–3714†°
MILWAUKEE: Milwaukee Astronomical Society, E. Halbach, 2971 S. 52nd St. (19). LI 1–1181†
OSHKOSH: Fox River Valley Amateur Astronomers Club, D. Zwicky, R. R. 5, Box 505. BE 5–7163†
RACINE: Racine Astronomical Society, Inc., Mrs. E. Howard, 4420 Shore Haven Lane. 632–8260†

[The information given here has been drawn from the lists given in *Sky and Telescope*, for whose kind assistance we are most grateful.]

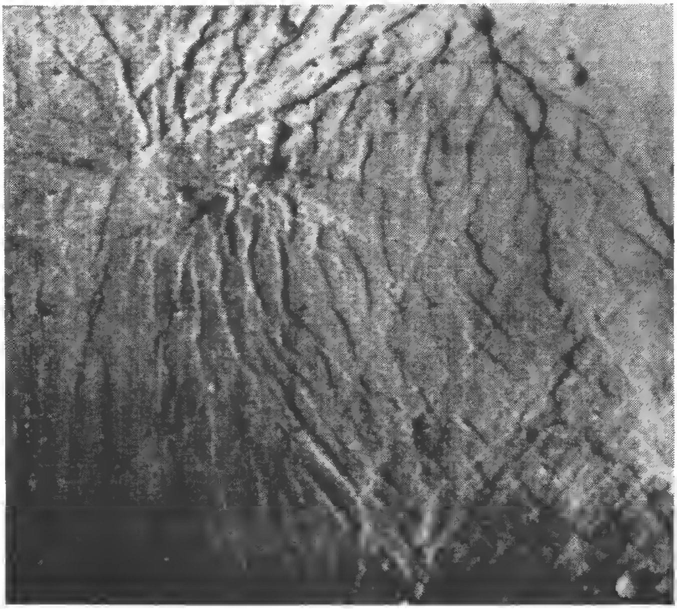

Fig. 3

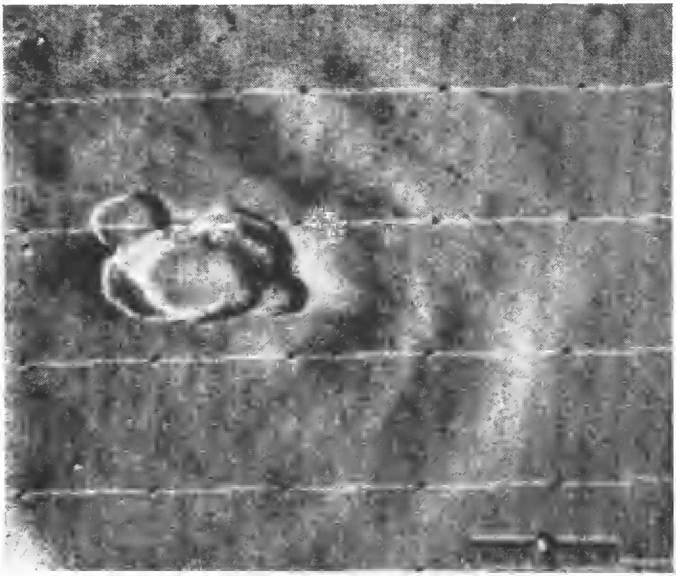

Fig. 4

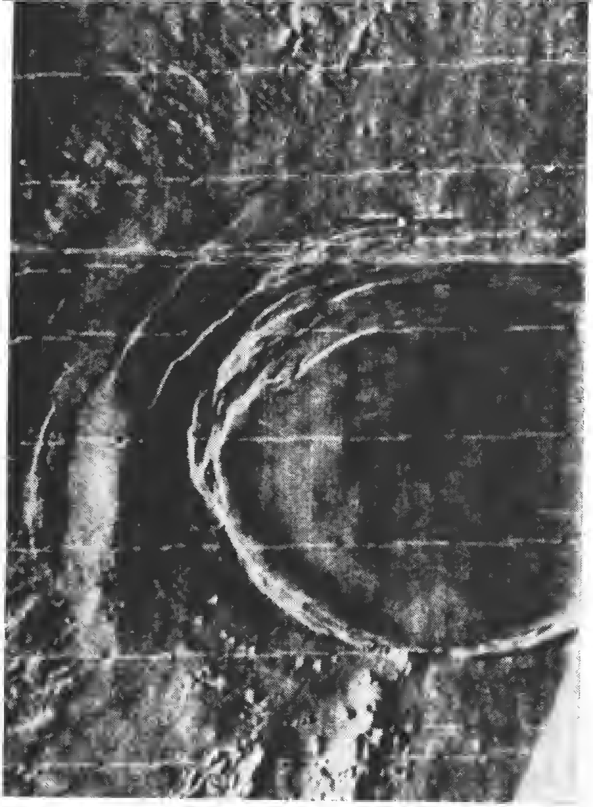

Fig. 5

Figure 1. This is one of the first photographs to be obtained of Phobos, the larger of Mars' two natural satellites. It is approximately 16 km by 22 km. The existence of craters on Phobos and its irregular shape make it with the other satellite Deimos, an extremely attractive target for research.
Figure 2. A mosaic of pictures taken by *Mariner 9* just prior to entering into orbit around Mars. The upper of the three prominent features in the centre has been identified as Arsia Silva, just south of the equator. It is about 200 km in diameter. The streaks pointing northwards are over 1000 km long.
Figure 3. A photograph of Phœnicis Lacus, taken after the dust storm had died down. Even so, all areas lying lower than 5·6 km above the surface are still hidden by dust. This photograph was taken on 17 December.
Figure 4. Mariner view of a complex crater near Ascraecus Lacus. It measures about 40 km across. The circular arcs surrounding the feature are thought to be atmospheric.
Figure 5. A 110 km diameter crater in the region of Nodus Gordii. The crater is on high ground and is protruding above the dust storm. This photograph was taken on 28 November. The multiple concentric fractures and the large number of small craters suggest that the feature may be a volcanic collapse crater.

Acknowledgement: All NASA photographs.

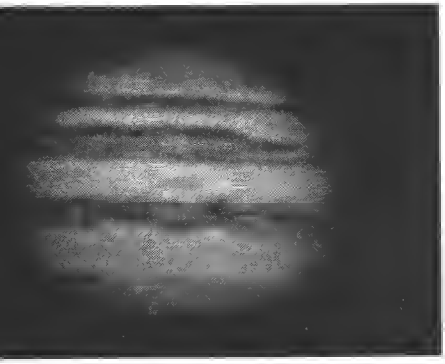

Fig. 1a

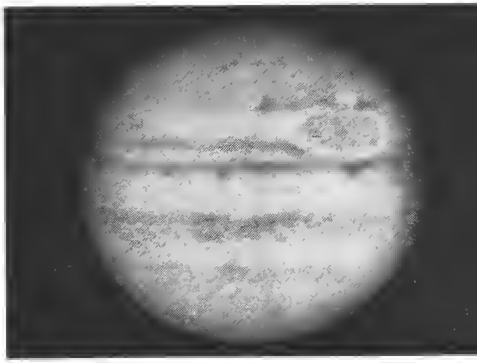

Fig. 1b

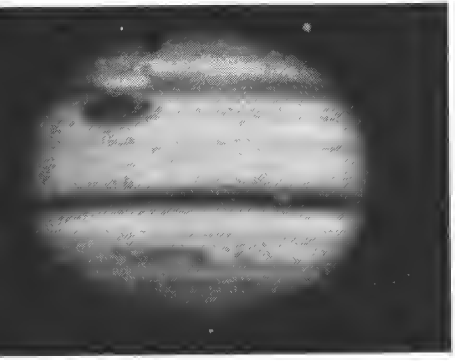

Fig. 1c

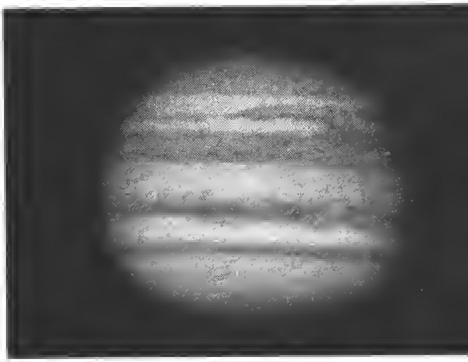

Fig. 1d

(Note that each picture shows the planet as seen in the northern hemisphere with an astronomical telescope – i.e., with the South Pole uppermost.)

(*a*) Photographed by E. C. Slipher with the 60 cm refractor at the Lowell Observatory, Flagstaff, Arizona, October 19 1915. [*Courtesy, Lowell Observatory*].

(*b*) Drawn by E. M. Antoniadi with the 82 cm refractor at the Meudon Observatory, Paris, May 22 1911.

(*c*) Photographed in blue light with the 200-inch (508 cm) reflector at Mount Palomar Observatory, California, October 24 1952. [*Courtesy, Mount Wilson and Palomar Observatories.*]

(*d*) Photographed by E. C. Slipher with the 60 cm refractor, Lowell Observatory, December 19 1917. [*Courtesy, Lowell Observatory.*]

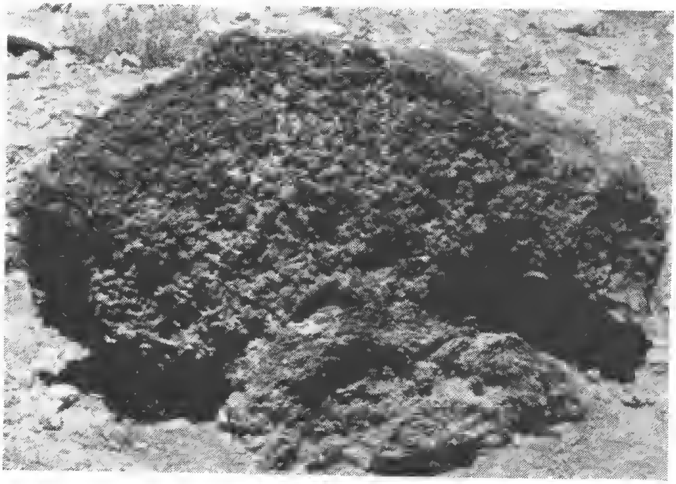

Fig. 2. A sample shed iron.

Station West and must also be paired with Mundrabilla, for it too is a shed iron. This iron was reportedly picked up some forty miles from the site of the main masses! The distribution of the shed irons is strange, but it is a very difficult matter for research, requiring an exhaustive programme and the setting up of a surveyed grid on a large area of the plain.

Two masses weighing 11 and 5 tons respectively were recovered from the Plain, and these are two halves of a larger single mass that entered the Earth's atmosphere, for they both show an identical shaped suture of separation, in the one case concave and in the other convex. The split occurred at some time during atmospheric entry prior to landing on the surface. The larger mass shows a similar undeveloped split, parallel to the surface of separation. The smaller, 5-ton mass somersaulted before landing and thus was found with the reverse side buried in the ground. The larger meteorite has the characteristics of an oriented mass, crudely resembling the familiar cone form of the space capsule and showing radial marks of ablation streaming of melted iron from the centre of the leading surface

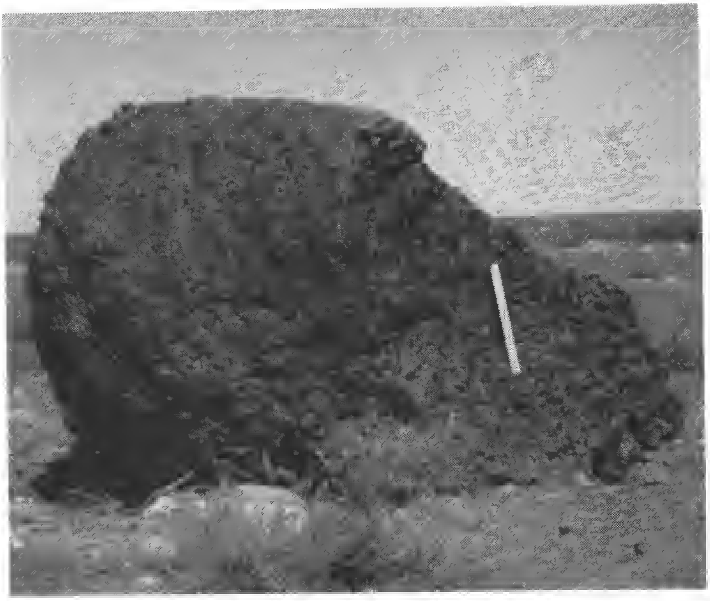

Fig. 3. The larger mass, M1, 11 tons, seen *in situ*. The spinifex grass has been cut away and the ground slightly excavated. Note the concave parting surface, with hackly protuberances, and the contrasting primary ablation surface, curved and striated. The mass drove in to the surface at a steeply oblique angle of descent, from the west (right). The shed irons probably separated from the hackly parting.

('stagnation point'), striations due to frictional dermal heating during atmospheric entry. After the split, the smaller mass tumbled in space due to instability, but prior to this the mass had not tumbled: probably the larger mass never tumbled, even after the split occurred, for the striated front of the cone drove into the limestone surface at a steeply oblique angle of approach from the west, and the mass remained in that position. There is some cracking of the limestone, but how much is simply due to normal weathering effects is difficult to estimate. The rock surface has suffered remarkably little deformation from the sudden impress of such a large mass of iron, and there is no sign of cratering beneath either mass.

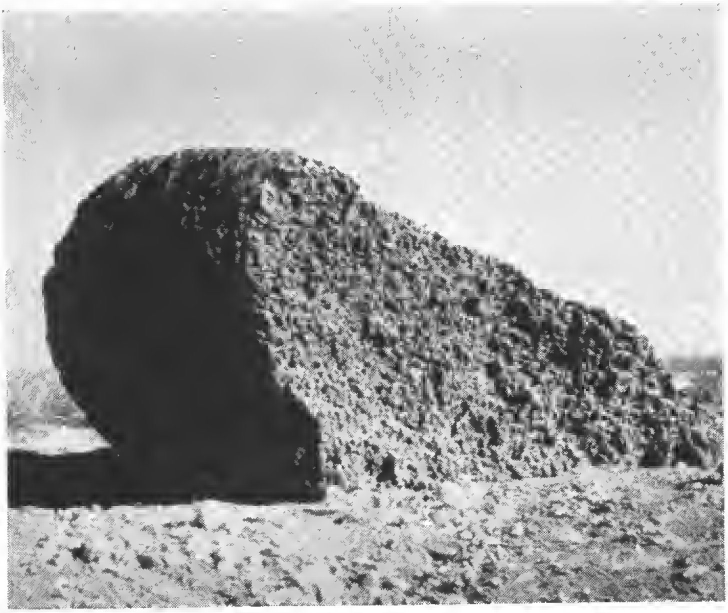

Fig. 4. The smaller M2 mass, 5 tons, seen *in situ*, showing the convex parting surface, complementary to that on the M1 mass (concave). The underlying pad of iron shale is well seen.
Both photographs reproduced in black and white from kodachromes by R. B. Wilson.

The small, shed irons are present by the hundred: an attempt to survey them was abandoned a few hundred yards from the main masses, for there appeared to be no end to them and no decrease in concentration. There can be no doubt that they were shed from the mass during ablation. No other large iron mass known is surrounded by such a satellite swarm of shed irons, all of inch scale and extending out from the large mass for at least twenty miles and probably more than forty. The small irons (quite distinct from the shale balls) surrounding Crater Mound at Canon Diablo, Arizona, and the small irons found 4 miles from the Wolf Creek Crater, Australia (McCall, 1968) may provide a limited analogy.

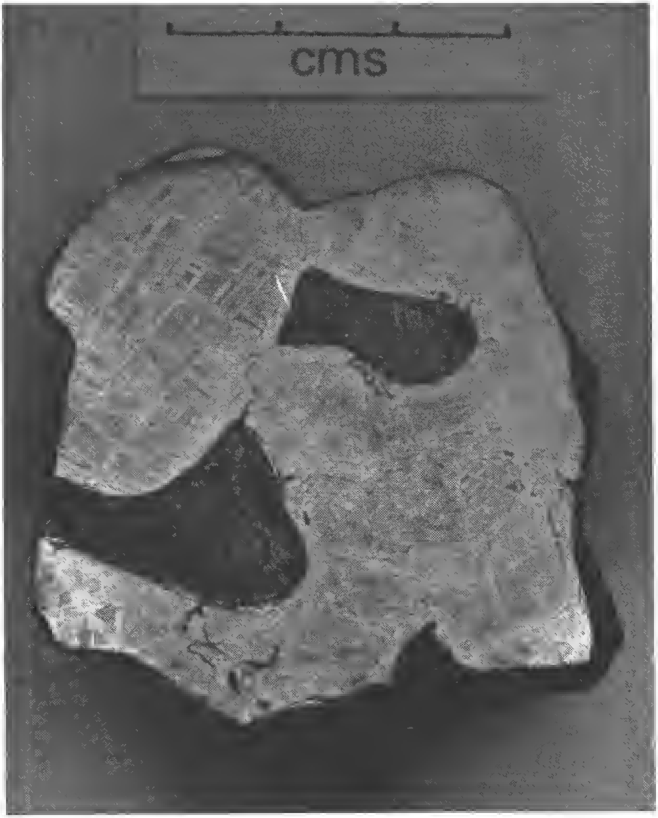

Fig. 5. The etch pattern showing on a polished, etched cut surface. The diverse orientation of small areas of Widmanstätten pattern is evident, together with areas of troilite and graphite (dark).

type known as a granular octahedrite, with silicate inclusions. Only three or four such meteorites are known, the most similar being one that fell in Soroti, Uganda. The mass consists of a proliferation of small areas of Widmanstätten pattern, tightly bonded together without intervening matrix or separated by areas of troilite and graphite (the former a sulphide of nickel

1973

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